Alaska Park Science

National Park Service
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Alaska Regional Office
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Climate Change in Alaska's National Parks

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...and more.

Volume 12, Issue 2

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Photograph courtesy of Joanna Young

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Earthquake Studies Reveal the Magmatic Plumbing System of the Katmai Volcanoes
Figure 2. Composite satellite image of the Katmai National Park and Preserve region. Modified image courtesy of Steve Smith and AVO/University of Alaska Fairbanks, Geophysical Institute.
cross-correlation analysis brings out those waves that happen to pass by both stations. An example is shown in Figure 5, where the ambient noise "seismograms" (known technically as Green's functions) for the Katmai area are lined up according to the distance between the two stations. The second step is the estimation of the velocity of the surface wave, which as noted above is a function of the frequency of the wave (a phenomenon known as dispersion), for all pairs of stations. The dispersion behavior is most sensitive to the S-wave velocity structure.
Images of the Seismic Velocity Structure
Figures 6 and 7 display slices through the three-dimensional models of the body-wave P and ambient noise S velocity models, respectively. Warm colors represent areas of the models with relatively low seismic wave velocity, and conversely cold colors represent areas with relatively high seismic wave velocity. We note that seismic wave velocity normally increases with depth (mainly due to the effects of increasing pressure), so areas that are anomalous can be identified by deviations from this general pattern.
There are several key features that we interpret in the P-wave (body-wave) model (Figure 6). One is the very low velocity at 2 km depth in the Katmai Pass

Climate Change in Alaska's National Parks

By Robert Winfree

Five years ago, during International Polar Year, we devoted an entire issue of Alaska Park Science to evidence of climate change in Alaska's national parks (NPS 2007). Although that became one of our most popular and award-winning issues, the environment for discussing climate change was mixed when we started work. That changed quickly with release of the Intergovernmental Panel on Climate Change's highly influential 4th Assessment (IPCC 2007) and with formation of a Climate Change Task Force in the Department of Interior (DOI). Within the next few years, two DOI secretarial orders on climate change had been issued (DOI 2009, 2010), the National Park Service (NPS) had established a Climate Change Response Program, and NPS had released climate change response strategies for the National Park System as a whole (NPS 2010a) and focused on the Alaska Region (NPS 2010b).

At the same time, readers were asking for more articles about climate change in Alaska Park Science, and we responded with a diverse set of articles on monitoring change (NPS 2010c), zooarchaeology (Etnier and Schaaf 2012), traditional knowledge (Krupnik 2009), visitors' perceptions (Brownlee and Halo 2011), wildland fire (Loya et al. 2011), wildlife (Joly and Klein 2011), and scenario planning (Winfree et al. 2011), to name a few. Today, we take pause again to reflect on climate change in even more depth, providing information about innovative approaches to ecosystem monitoring and research, vulnerabilities and impact assessments, modeling and predicting future change, and planning for and communicating change.

In this issue, authors Carny and Wesser, Gray et al., and DeGange et al. report on state-of-the-art landscape-scale approaches to ecosystem monitoring, research, and modeling that could scarcely be envisioned a few years ago. Roland shares evidence of landscape-level change from historical repeat photography at Denali, and Elias describes how fossilized Beringian insect remains can reveal vegetation changes over thousands of years into the past.

Swanson provides an overview of dramatic changes that are becoming increasingly apparent as permafrost thaw expands further into arctic landscapes. Loso et al. report on glacier change detection from a high-level regional perspective, and Young reports on her detailed investigation on one glacier. Glaciers are frozen reservoirs that release fresh water as they melt, so when glaciers change it can also mean changes to seasonal water supplies. Milner's long term ecological research shows how differences in stream flow also affect stream life.

It is vitally important for people to understand that climate change is not just an academic issue for scientists and natural, cultural, and scenic resource managers. Geertsema and Callaway explain how "front line" impacts of climate change can be dramatic, life-changing, and sometimes life-threatening for people who work, live, and travel in the midst of such changes.

But how should parks respond to the challenges of climate change? Over the last few years, and with support from the NPS Climate Change Response Program and others, Winfree et al. organized climate change scenario planning workshops for parks, partners, and communities across Alaska. In this issue they summarize the information needs and management actions identified by hundreds of participants, with full reports posted on the project website (http://www.nps.gov/akso/nature/climate/scenario.cfm). Rice et al. describe how forward-looking NPS planners can assess and mitigate impacts to existing assets, while developing new approaches for factoring climate change uncertainties into future planning. Morris et al. describes climate change interpretive and educational initiatives by NPS and partners, and Conners reports on a multi-faceted hands-on approach to climate change education, where high school students combined traditional knowledge, historical accounts, and boots-in-the-mud fieldwork to discover how Glacier Bay's environment, resources, and people have changed over multiple time frames—lessons they will remember for a lifetime.

It is very clear that climate change is a fast-changing field of study. For anyone with more than a passing familiarity with Alaska, it's also clear that major changes to ice, sea level, flora, and fauna have occurred here for thousands of years. What's different now is that the changes are happening faster—fast enough for people to sense and recognize. The myriad ways in which climate change is affecting our lives, environment, resources, and the places we care about, will be incompletely understood for long into the future—but waiting for complete certainty before responding is unlikely to be a viable solution. The activities described in this issue, and others like them, bring us closer to the goals outlined in the NPS Alaska Region's five-year climate change response strategy (NPS 2010b). We hope this issue of Alaska Park Science provides new insights about what climate change means for Alaska's national parks, and sparks discussion about how the National Park Service and its partners are responding to the challenge.

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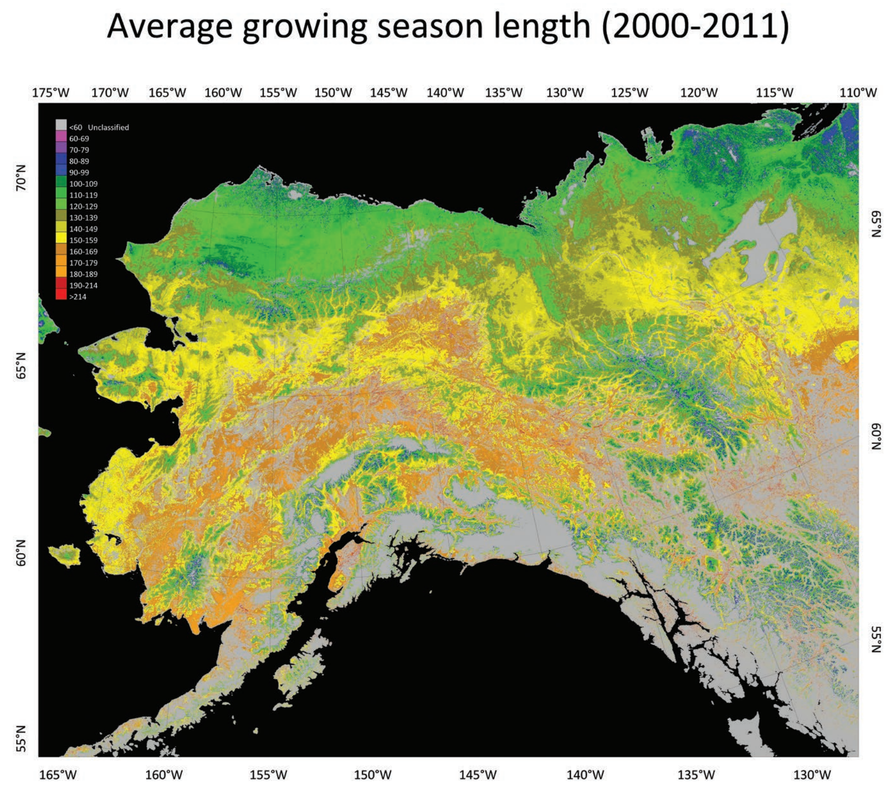
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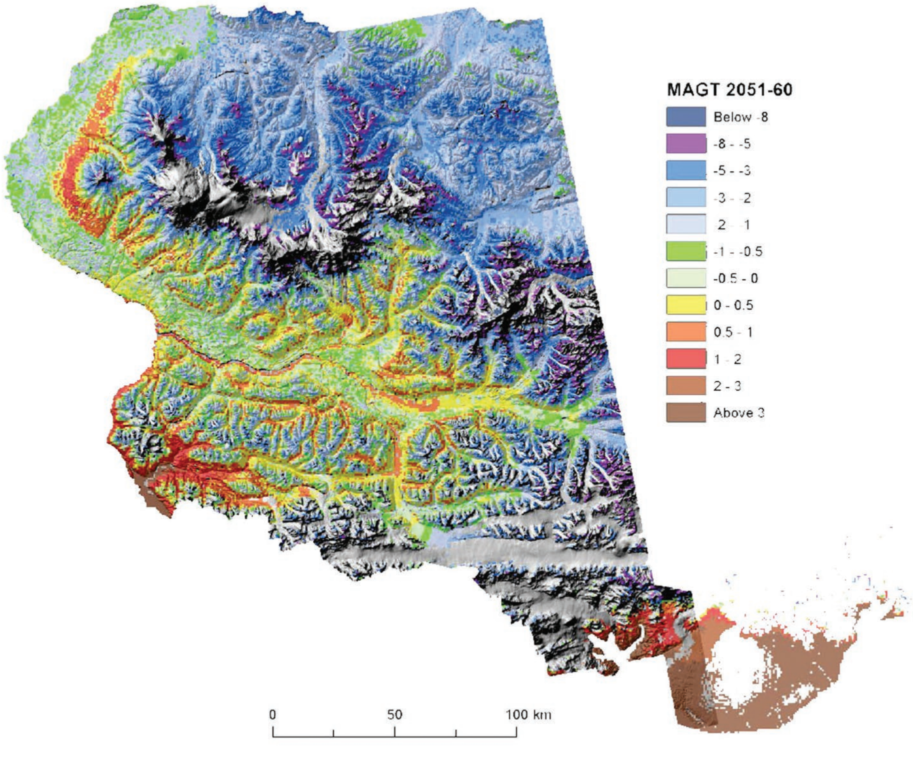
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Monitoring the Vital Signs of Alaska's National Parks

By Brooke Carney and Sara Wesser

By design, the National Park Service's Inventory and Monitoring (I & M) program identifies key resources in national park units, called vital signs, then sets out to document and track the condition of those resources using rigorous protocols (Fancy et al. 2009). In addition, important drivers of changes in resource condition, including climate change, are incorporated into the monitoring either by direct monitoring (e.g. weather) or by monitoring resources impacted by the drivers in question. In recent years, established monitoring programs have reached a point of delivering results and trends. In addition, supplemental funding has enabled I & M to oversee several studies aimed at assessing the current and potential impacts of climate change.

Figure 1. NPS biologists record data as part of the Central Alaska Network's long-term vegetation monitoring program in Denali. Their work was summarized and published in the February 2013 edition of Ecological Monographs.

Figure 2. (map, top) Variation in average growing season length across southwest Alaska, as inferred from MODIS NDVI data collected between 2000 and 2011. Legend shows approximate growing season length in days. In Katmai, the growing season is shortest at higher elevations and longest in the lowlands surrounding the Naknek and Alaganak Rivers.

Figure 3. (map, bottom) Partners at UAF are using NPS inventory and climate data to model future permafrost coverage for all Alaska parks. This map shows Wrangell-St. Elias National Park and Preserve for the time period 2051-2060. Cooler colors represent cooler ground temperatures.

Established Monitoring Programs—Delivering on the Promise

In the early years of the I & M program, focus was placed on the selection of key resources (vital signs) and on designing monitoring programs to track the status of the selected vital signs. Established monitoring programs are now starting to deliver results on the condition of vital signs, and in the process, they are not only telling us the story of these resources, but how climate change may be affecting parks, now and in the future.

Recent studies suggest that climate warming in interior Alaska may result in major shifts from spruce-dominated forests to broadleaf-dominated forests or even grasslands. To quantify patterns in tree distribution and abundance and to investigate the potential for changes in forest dynamics through time, the Central Alaska Network initiated a spatially extensive vegetation monitoring program covering 3.2 million acres (1.28 million ha) in Denali National Park and Preserve. In early 2013, Carl Roland, Fleur Nicklen, and Josh Schmidt published an article in the prestigious journal Ecological Monographs describing the landscape patterns they observed during the decade-long study (2001–2010). In contrast to some previous studies, the authors report that white spruce (Picea glauca) may respond favorably to warming conditions by increasing in abundance and distribution by expanding into newly thawed terrain. In addition, this study reports no current evidence for a large-scale shift from spruce to broadleaf forests in the lowlands of Denali National Park, where coniferous forests still dominate the landscape (Roland et al. 2013).

Vegetation monitoring was established in Denali in the mid-1990s. In 2001, the new study design was implemented across a large area in the northern portion of the park as part of the Central Alaska Network's monitoring efforts (MacCluskie et al. 2005). The tree data presented in the 2013 article present one facet of the vegetation monitoring program data, whose overall goal is to establish a robust, statistically rigorous baseline for important aspects of vegetation structure and composition at a landscape scale that will allow us to detect changes in these attributes over time. In 2013 and 2014, sampling efforts using the same protocol will be focused in Yukon-Charley Rivers National Preserve.

Tracking Growing and Winter Season Processes

Globally, leaf-out and flowering dates are occurring earlier in the spring, and fall colors are turning later. Across Alaska, the I & M Program is using MODIS satellite data to track variation in growing season length (Normalized Difference Vegetation Index, or NDVI) as well as snow cover metrics. As NDVI—an indicator of vegetation productivity—increases in the spring and declines in the fall, it provides an approximation of when the growing season starts and ends.

To date, data for NDVI has been analyzed for ten-year periods in the Southwest Alaska and Arctic Networks. While no strong trends of change have been detected in southwest Alaska for 2001–2010, NDVI values for late June steadily increased from 1990–2009 in the Arctic Network. This shift reflects an increase in plant biomass which is likely due to warming (Swanson 2010). This initial data serves as a baseline dataset and positions the I & M program to track and identify future

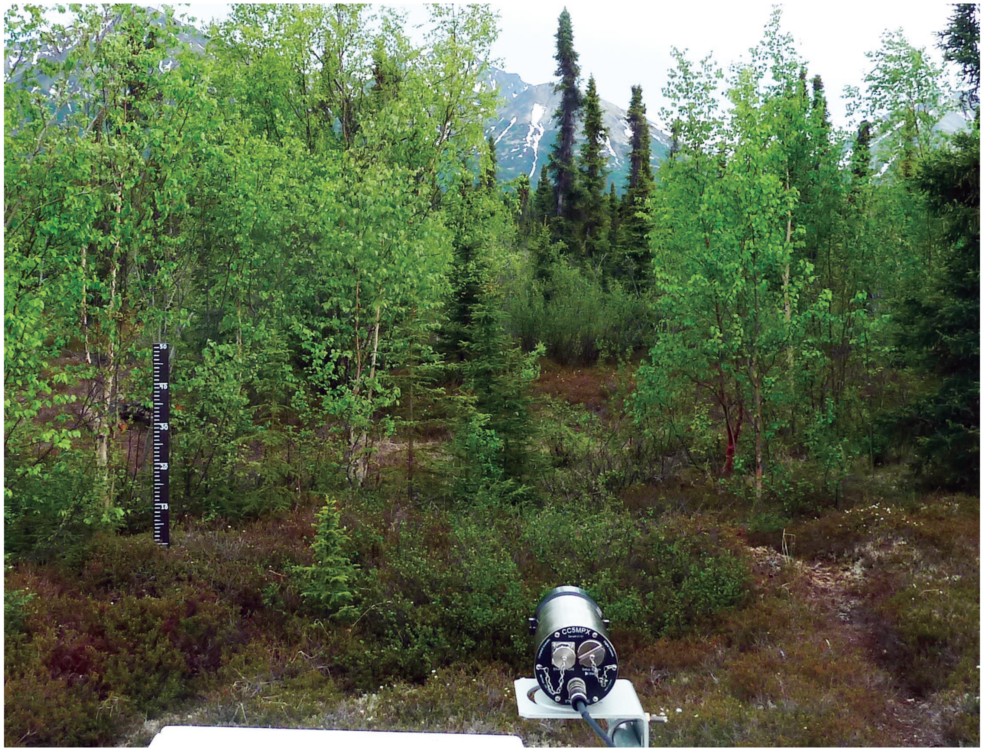

Figure 4. Cameras like this one in Lake Clark National Park and Preserve are set up on climate stations throughout the state. Photos captured by the "phenocams" supplement phenology and climate data collected by other means.

changes in growing and winter season processes.

In addition to accomplishing the goals of the monitoring programs, this effort is now leading to new collaborations as scientists and agencies seek out the data made available by the efforts of NPS and Geographic Information Network of Alaska (GINA). The I & M program led and funded the effort to obtain data for NDVI and snow metrics, and as a result of their efforts, data for all of Alaska is now publicly available for the 2001-2011 period via the GINA.

Responses to Warming in Katmai and Lake Clark

Regional warming over the last several decades is thought to have contributed to widespread mortality in spruce forests of southwest Alaska, but also to often-enhanced growth in trees at the western forest-tundra ecotone (Beck et al. 2011). As part of the vegetation composition and structure vital sign monitoring program in the Southwest Alaska Network, NPS staff and collaborators at Humboldt State University are using tree-ring and plot-level data to better understand stand tree growth-climate interactions in white spruce woodlands. Forest monitoring plots located in low-elevation, open spruce stands are arrayed across a 300-km north-south transect that spans Lake Clark and Katmai National Parks and Preserves.

All trees analyzed to date have shown increased growth in the last 10-30 years. Trees in the northernmost sites show the earliest response to warming with increases in growth appearing a decade or more ahead of trees in plots at the southern end of the transect. The positive growth of white spruce in response to warming in this area contrasts with the decreases in growth often seen in drought-stressed trees in interior Alaska. While the project is ongoing, field work on tree growth responses concluded in 2013. Final analysis, including comparisons of growth patterns to climate data, is scheduled for completion in early 2014.

Enhanced Monitoring Efforts Assess Impacts of Climate Change

In 2010, the National Park Service adopted the Climate Change Response Strategy. The strategy lists science as one of the four platforms by which NPS will respond to climate change, and under that platform it states that NPS will "inventory and monitor key attributes of the natural systems… likely to be affected by climate change." Using funds associated with the adoption of the Strategy, the Alaska I & M program funded four initiatives addressing information needs for several existing vital signs. These initiatives have enhanced existing efforts and position the I & M Program to assess future changes using the newly obtained baseline data.

Glaciers in Alaska's National Parks

It's no secret that the iconic glaciers of Alaska are vulnerable to climate change. However, until now no comprehensive inventory of the status and trends of all glaciers in Alaska's national parks has been conducted. The glacier inventory, a three-year project by partners at the University of Alaska Fairbanks and Alaska Pacific University, is nearing completion. Detailed surface elevation profiles and extent maps have been developed for all glaciers. For those with multiple data sets, changes in extent have been quantified. In addition, estimates of change in total volume have been made for some glaciers (Arendt et al. 2012). Progress reports are currently available via IRMA (Integrated Resources Management Applications Data Store).

By the close of 2013, a final report as well as an additional interpretive report of 20 focus glaciers will also be available (see Loso in this issue). Data from this project will become part of a global glacier inventory housed and distributed by Global Land Ice Measurements from Space (GLIIMS). Investigators working on the NPS glacier project developed the data sharing model that has now been adopted by GLIMS and applied to the broader global inventory of glaciers. This extensive dataset not only tells us how the glaciers have changed over the last fifty years or so, but also positions us with the information needed to track future changes.

Permafrost in Central Alaska

Roughly 80% of Alaska is underlain by permafrost—ground that is permanently frozen. As the climate warms, permafrost is expected to melt. As it melts, it will change the landscape. To gain a more complete understanding of current permafrost conditions in Alaska's national parks and to predict future conditions, several projects were initiated with enhanced climate change monitoring funds.

The first project, conducted by partners at the University of Alaska Fairbanks, uses existing NPS soils and landcover inventory data as well as NPS weather data as inputs to develop maps of current permafrost conditions and to model future conditions in all parks (Romanovsky et al. 2012). This project will produce maps of current and likely future permafrost conditions for all parks in the Arctic and Central Alaska Networks. Phase one of this project is scheduled for completion in 2014.

To expand upon the work previously done in the Arctic Network parks, two additional projects were funded in Yukon-Charley Rivers and Wrangell-St. Elias. Permafrost related features were inventoried and mapped in specific areas within the park units (Wells 2013a and 2013b). The projects in Yukon-Charley and Wrangell-St. Elias both focus on areas of importance to the parks and will serve as management tools for future action.

Monitoring Phenology on the Ground

To supplement and ground truth the MODIS satellite data being used to track seasonal processes, several time-lapse cameras were purchased with enhanced climate change monitoring funds. While satellite imagery provides information on a landscape-scale, the cameras provide more localized information, showing additional details such as breaks in snow cover during a winter season. The cameras are mounted to existing climate monitoring stations in Katmai, Lake Clark, and Kenai Fjords National Parks. Six additional cameras are mounted to climate stations in the Central Alaska and Arctic Network. Several images are captured daily from early spring to late fall. The daily images from cameras are then analyzed to estimate the timing of green-up (start of the growing season) and leaf-fall (end of the growing season) at each site. Imagery collected by the cameras is shared with the National Phenocam Network. The images from the time-lapse cameras in southwest Alaska align with the satellite imagery confirming the validity of remote sensing techniques for detecting green up at large spatial scales.

Conclusion

One of the core purposes of the Inventory and Monitoring Program is to track the status and trends in the condition of natural resources in our national parks. In Alaska, the I & M program is transitioning from design and data collection to a phase that also includes delivery of results. Knowing the status and trends in the condition of natural resources serves as the foundation from which management decisions are made and the public is informed. As the impacts of climate change become more visible and recordable, this foundation of knowledge becomes increasingly important.

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Using Integrated Ecosystem Modeling to Understand Climate Change

Stephen T. Gray, Alec Bennett, W. Robert Bolton, Amy L. Breen, Tobey Carman, Eugenie Euskirchen, Helene Genet, Elchin Jafarov, Jennifer Jenkins, Tom Kurkowski, Michael Lindgren, Philip Martin, Stephanie McAfee, A. David McGuire, Sergei Marchenko, Reginald Muskett, Santosh Panda, Joel Reynolds, Amanda Robertson, Vladimir Romanovsky, T. Scott Rupp, Kristin Timm, and Yujin Zhang

Introduction

By any measure, climate change promises to bring major impacts to parks and preserves in the Alaska region. We know with great certainty that temperatures will continue to increase in coming decades, and warming will undoubtedly be accompanied by some combination of altered precipitation regimes, changes in seasonal weather patterns, and shifting extremes (IPCC 2007). However, one of the greatest challenges for park managers and planners is in connecting these climate drivers to the actual resources they must manage and protect. At the end of the day, climate projections suggesting ranges of temperature increase or upper and lower bounds on variables like seasonal precipitation have limited practical value for shaping policy and guiding investment. In-and-of themselves climate projections offer little actionable information. Climate projections only take on meaning in the context of park adaptation management and planning when they can be linked to impacts on the resources, services, and amenities these lands provide.

Figure 1.

Fortunately, we have a growing set of tools to help us address the challenge of linking changes in climate to the physical, ecological, and cultural systems that make up our parks and preserves. We can, for example, rely more and more on observed links between park resources, climate variability, and climate change gleaned from field observations. Efforts such as the US National Park Service's (NPS) Inventory and Monitoring program are particularly valuable in this sense (http://science.nature.nps.gov/im). Likewise the NPS' use of Scenario Planning (Weeks et al. 2011) is helping park managers and stakeholders envision the potential range of future climate change impacts, while also providing a platform for exploring adaptation and mitigation options.

Here we describe another approach centered on the use of modeling to connect climate-change drivers to tangible on-the-ground impacts in parks. At the most basic level, the Integrated Ecosystem Model (IEM) for Alaska and Northwestern Canada ingests climate scenarios (historical or projected future) and, in turn, uses tightly interconnected simulations of key physical and ecological processes to produce estimates of future landscape response. The IEM is focused on producing spatially-explicit (e.g., map-based) outputs that can serve as stand-alone decision support tools. This effort is also designed to produce information that can be integrated into many of the tools used by resource managers and planners. Such process-based simulations are of vital importance because they offer us the ability to explore novel climate-ecosystem-resource interactions and potential events that may be outside the bounds of available observations.

The IEM domain covers most of Alaska, the Yukon Territory, and portions of northern British Columbia (Figure 2). This domain was originally chosen to coincide with the Arctic, Western Alaska, and Northwest Boreal Landscape Conservation Cooperatives (http://alaska.fws.gov/lcc), and the northern portion of the North Pacific LCC. The domain is also governed by practical concerns. For instance, portions of the Northwest Boreal LCC in the Mackenzie and Selwyn Mountains area are not included in the domain due to a lack of critical climate data. Similarly the Aleutian and Bering Sea Islands are also not included because the heavily maritime-influenced processes at work in these areas are not well represented by the IEM. Just as this general modeling approach allows us to consider climate-ecosystem scenarios beyond those captured in the observational record, this large, cross-border domain is intended to help us understand cross-boundary processes.

Building an Integrated Ecosystem Model

Three models that depict different components of high latitude landscapes provide the basic building blocks of the IEM. Collectively these individual models have been used in hundreds of ecosystem impact studies. All three have a long track record of applications in Alaska and northwest Canada, including previous work in the context of parks and preserves (e.g., Loya et al. 2011). However, this new IEM effort represents the first time these tools have been brought together in a coupled fashion, thereby allowing us to more fully understand feedbacks and interactions between the many interconnected elements of high-latitude landscapes. It is also worth noting that all three of these building blocks emphasize spatial patterns in ecosystem variability and change, as will results from the full IEM.

The Alaska Frame-Based Ecosystem Code (ALFRESCO) is being used to simulate vegetation dynamics

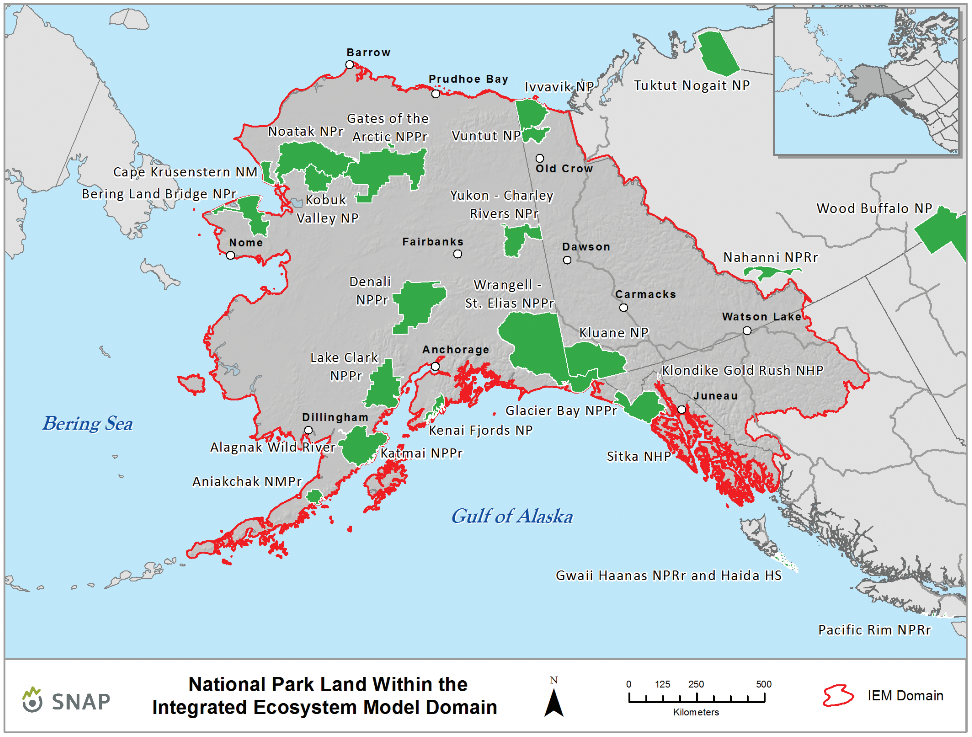

Figure 2. The geographic domain for the Integrated Ecosystem Model. The IEM effort encompasses numerous parks and preserves (shown in green) in Alaska and northwest Canada. Map courtesy of the Scenarios Network for Alaska and Arctic Planning (SNAP).

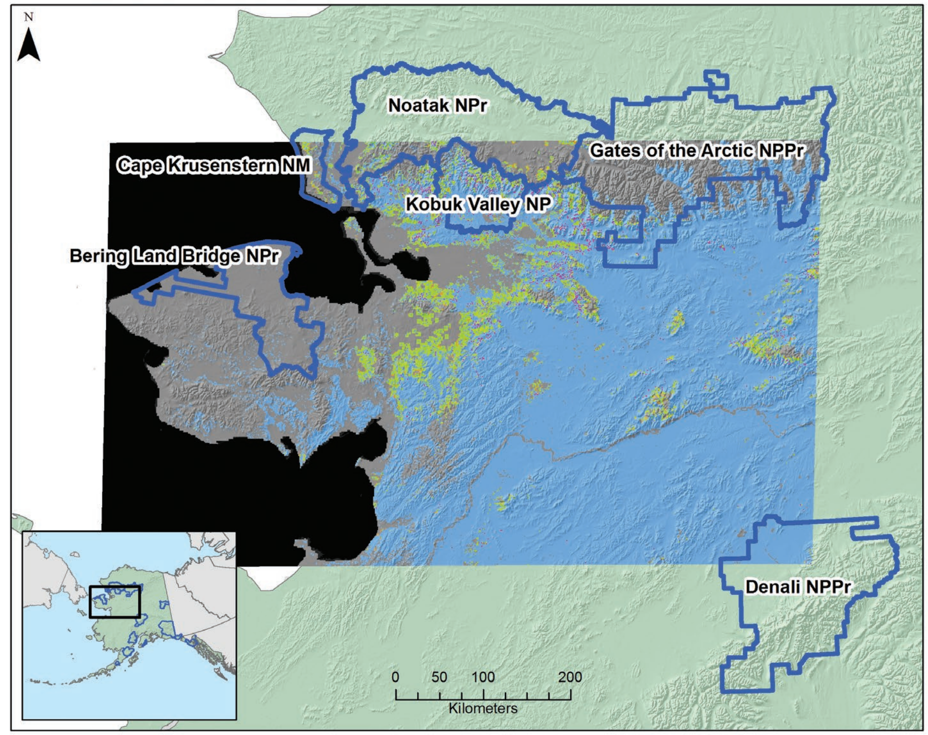

Figure 3. Preliminary output from the ALFRESCO component of the IEM showing areas in northwestern Alaska where tundra may transition to spruce forest (shown in yellow) by 2100. The model was driven by air temperature and precipitation from a single climate model (CCMA) with forced under the A1B emissions scenario (IPCC 2007). However, full IEM model runs will consider projections from multiple climate models run under various emissions scenarios.

including establishment, succession, and migration (Figure 3), along with disturbance processes such as wildland fire and insect outbreaks (Rupp et al. 2007). ALFRESCO was originally designed to model the dominant landscape-scale processes in boreal forest ecosystems, and it has been successfully applied in National Park Service units from Interior Alaska including Denali National Park and Preserve, Yukon-Charley Rivers National Preserve, and Wrangell-St. Elias National Park and Preserve. Meanwhile, recent updates have greatly enhanced its utility for understanding changes in shrub and tundra ecosystems. More specifically, the latest ALFRESCO development work has focused on the ability to capture potential transitions between conifer and broadleaf dominated vegetation types, and to track shifts in both latitudinal and altitudinal treeline. Likewise, work on ALFRESCO is also moving towards improved depictions of the dominant ecosystem types found in Southeast Alaska, and in particular the coastal temperate rainforest. The application of ALFRESCO to Southeast Alaska is especially important and exciting as it will give us a chance to explore processes and potential climate-vegetation interactions with little or no historical precedent. For example, some climate-change projections suggest the possibility of emerging drought impacts in Southeast Alaska. If that were the case, drought conditions could also introduce the chance for fire and novel pest outbreaks. Because we have no observed analogs for these types of situations in southeast Alaska, it is vitally important that we be able to simulate related dynamics within the context of the IEM.

The second basic component of the IEM is the Terrestrial Ecosystem Model (TEM; Yi et al. 2010). TEM is used to describe fundamental terrestrial ecosystem processes, while also giving us insights into related hydrologic variability. In short, TEM simulates the movement of carbon, nitrogen, and water through plants and soils based on inputs including climate, vegetation type, elevation, solar radiation, and substrate. TEM has been widely used to understand how different scenarios for climate variability and climate change might affect net primary productivity and other critical ecosystem characteristics at regional to global scales. In the case of the IEM project, however, special attention is being given to the ability of TEM to portray changes in the quantity and quality of forage available for ungulate consumption. Moreover, the IEM team is looking at multiple ways to improve the representation of hydrology at high latitudes. As one example, the IEM team has formed a working group focused exclusively on the modeling of wetland and thermokarst dynamics via TEM. At the same time, members of this wetland-thermokarst group are conducting field experiments and collecting real-world observations to feed into these simulations. Similarly, IEM team members have begun preliminary work to better account for the contributions of glaciers and snowmelt to regional hydrology in southeast and southcentral Alaska. Overall, the resulting spatially-explicit representations of plant productivity, plant community types, nutrient fluxes, and water availability will be critical for resource managers as they seek to understand the impacts of climate change on parks, preserves, and other large natural areas. In addition, once fully coupled with the other components of the IEM, output from the TEM-based simulations will give us a unique look at how large parks and preserves can serve as sources or sinks of carbon, and thus help us better appreciate the significance of these lands in a global context.

Lastly, the Geophysical Institute Permafrost Lab (GIPL; Jafarov et al. 2012) model is being used to simulate permafrost dynamics in the Arctic and sub-Arctic ecosystems of Alaska and northwest Canada (Figure 4). In essence the GIPL model simulates changes in the ground thermal regime as driven by inputs of climate, vegetation, soils, topography, and geology. Snow distribution and the role of snow as a ground insulator are also major players in GIPL. As heat moves through the simulated ground layers, water freezes and thaws, and GIPL thus yields spatially-explicit information on permafrost extent, ground temperatures, active layer thickness, and freeze/thaw regimes over time. While the IEM team anticipates that related outputs will be of interest in areas currently underlain by more-or-less continuous permafrost, the most significant results for parks and resource management are likely to come from areas that now feature discontinuous permafrost. Because changes in permafrost can trigger substantive changes in hydrology, further development of the GIPL module is proceeding in close cooperation with the wetlands and thermokarst group

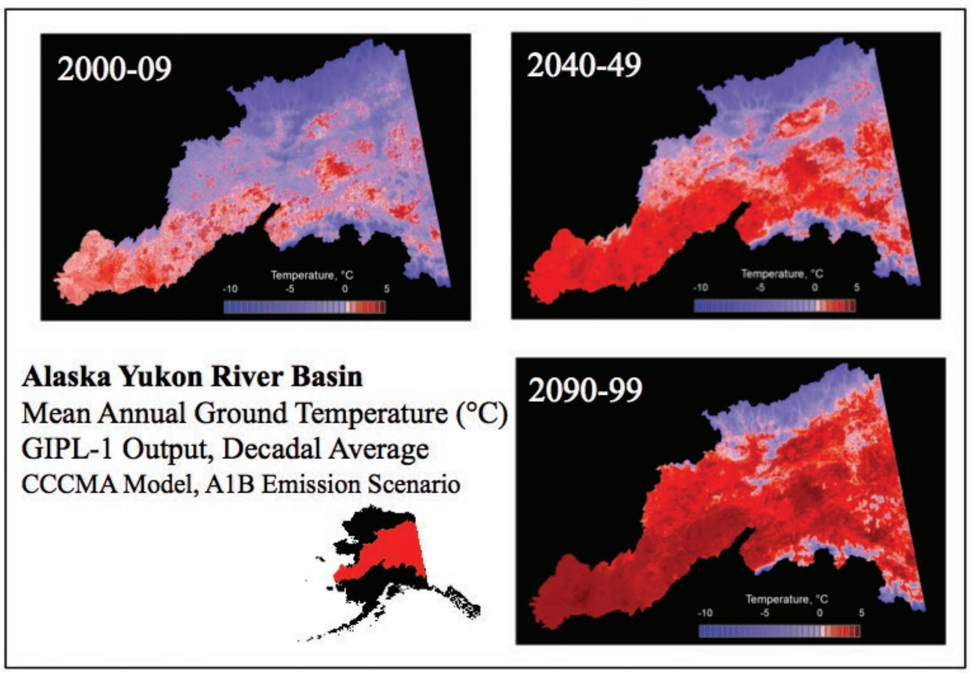

Figure 4. Preliminary output from the GIPL permafrost module of the IEM showing the simulated distribution of near-surface permafrost as indicated by mean annual ground temperatures at 1 m depth (blues – temperature < 0° C and red – temperature > 0° C) in the Alaska portion of the Yukon River Drainage Basin for the decades 2000-2009, 2040-2049, and 2090-2099.

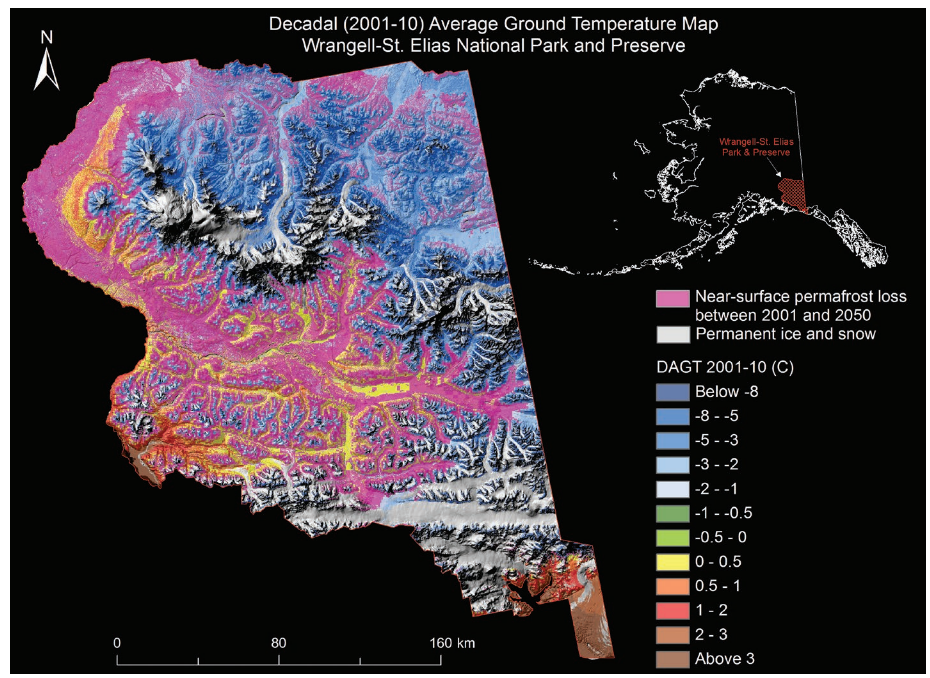

Figure 5. Preliminary output from the GIPL module of the IEM running in high resolution (30m x 30m) mode. The map shows decadal average ground temperatures during the period 2001-10 for Wrangell-St. Elias National Park and Preserve overlain with areas susceptible to active near-surface permafrost thawing (shown in pink) by 2051-60.

mentioned earlier. Special attention is also being given to the relationship between permafrost change, lakes, and rivers. Late 2013 should also see the start of major efforts aimed at understanding how climate change and associated permafrost dynamics might impact infrastructure and access to resources in parks and preserves (e.g., Figure 5).

Progress to Date

While the IEM is still in its developmental phases, much has been accomplished. The project began in earnest during 2010-2011 with a pilot exercise focused on the Alaska portion of the Yukon River Basin. The central feature of this exercise was a proof-of-concept model run linking ALFRESCO, TEM, and GIPL in a simple, linear fashion where the component models communicated sequentially. This pilot work was especially helpful for evaluating the degree to which feedbacks between forest types and fire regime might alter organic soils and permafrost under climate warming (Rupp et al. 2012). Likewise it also pointed out the need to better model certain elements of wetland hydrology.

More recent accomplishments include the final compilation of downscaled climate datasets (historical and future projections) for use in driving the IEM. Similarly, biophysical parameters have now been developed for the entire project domain. Of particular note, these input variables include a newly developed 820 ft (250 m) resolution vegetation map based on the North America Land Change Monitoring System model (CEC 2010).

The individual ALFRESCO, TEM, and GIPL models have been "cyclically" coupled over the past year. In short, this involves assembling all of the models on a common computer platform, and then allowing them to communicate at regular time intervals. In a technical sense the current mode of operation is something just shy of the fully-coupled, dynamic framework envisioned for the IEM. However, this still represents an enormous accomplishment in terms of computer programming and hardware, software, and data integration. Other major milestones include the development of new algorithms describing tundra fires and tundra-treeline dynamics, selection of conceptual approaches for representing thermokarst dynamics at management-relevant spatial scales, and continued field studies that provide insight into carbon and vegetation dynamics in boreal fens and collapse-scar bogs resulting from thermokarst formation.

IEM is focused on generating datasets that can be directly applied to natural and cultural resource management and planning. Plans for distributing IEM output emphasize free and easy access. Moreover, derivative products and the underlying source code will be made available to the management and scientific research community alike. General categories of data products include maps depicting historical and future climate; vegetation types, landcover and landscape structure; disturbance types, frequencies and intensities; key ecosystem processes; soil properties; and

Example Data Products from the Integrated Ecosystem Model

Dataset name	Data type	Description
Historical and projected average monthly temperature, precipitation, radiation, and vapor pressure	Spatial	Downscaled historical grid-based products and downscaled projections of monthly temperature, precipitation, radiation, and vapor pressure from multiple sources.
Treeline extent	Spatial	Maps depicting projected treeline change under selected climate scenarios.
Potential vegetation distribution	Spatial; Tables/graphs	Modeled distribution of dominant vegetation types (e.g., black spruce or shrub tundra). Graphs showing changes in area of vegetation types through time.
Area burned and burn severity	Spatial; Tables/graphs	Maps and graphs that depict simulations of area burned and burn severity under selected climate scenarios.
Potential susceptibility to thermokarst formation	Spatial	Results of model runs used to identify areas susceptible to thermokarst disturbance. Datasets may include fractional coverage of thermokarst/wetland landforms, distance from surface to ice rich permafrost, amount of ice in the soil column, drainage efficiency (parameter that describes the ability of the landscape to store water), and soil water content.
Carbon fluxes and pools	Spatial; Text; Tables/graphs	Model output related to carbon fluxes (GPP, Net Primary Productivity, decomposition, carbon released by fire, etc.) and carbon pools in soil and vegetation.

Table 1. Examples of anticipated products emerging from the Integrated Ecosystem Model.

permafrost distribution and dynamics (Table 1). The IEM team will provide thorough documentation describing the modeling process, along with practical, user-friendly descriptions of model uncertainty.

Conclusions

Modeling that links climate to ecosystem processes is certainly not the only means for parks and other resource managers to connect climate change with real world impacts. However, climate-driven ecological process modeling such as the IEM effort has several important strengths. In particular it allows us to consider ecosystem- and landscape-change scenarios outside range of historical experience. Such approaches also give us a tool for exploring complex feedbacks, interactions, and threshold responses that may not be evident from field studies or other observations. Overall, linking ALFRESCO, TEM, and GIPL will produce a more realistic picture of future ecosystem conditions and, in turn, help us more effectively plan for climate change and manage the resources these lands provide.

Acknowledgements

The authors wish to thank Paul Duffy, Zhaosheng Fan, Guido Grosse, Dustin Rice, David Swanson, Mark Waldrop, and Feng-Ming Yuang for their contributions to this effort. Funding for this work was provided by the Alaska Climate Science Center; Arctic, Western Alaska, and Northwest Boreal Landscape Conservation Cooperatives; and the National Park Service's Climate Change Response Program.

Further information is available at:

http://www.doi.gov/csc/alaska/

http://csc.alaska.edu/

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Status and Trends of Alaska National Park Glaciers: What Do They Tell Us About Climate Change?

Michael G. Loso, Anthony Arendt, Chris Larsen, Nate Murphy, and Justin Rich

Introduction

Most visitors to Alaska's National Parks are by now familiar with the fact that the state's many glaciers are changing. Many glaciers are shrinking, and "retreat" of the glacier terminus is usually the most obvious manifestation of that change. But while some glaciers (like the Yahtse Glacier in Wrangell-St. Elias National Park and Preserve, Figure 2) have experienced dramatic retreat over the last century or so, others appear surprisingly stable. And a handful of glaciers are actually advancing. Given this complexity, and the importance of glacier changes for issues ranging from road maintenance to global sea level, it may surprise many visitors to find out that until recently, NPS lacked the most basic tool for understanding these changes: a comprehensive inventory of the glaciers in its parks.

Prior to the work we describe here, many of Alaska's glaciers had not been remapped since the US Geological Survey made its original topographic maps in the 1950s and 1960s—maps that modern backcountry travelers still use, but have learned to view with some skepticism when navigating through glaciated terrain. Figure 2 provides a striking example: according to the USGS topographic map for western Icy Bay, the scientists on that rocky beach should be under at least 175 meters of ice. That map, based on 1957 aerial photography but still available to the public, shows the Yahtse Glacier terminus over 5 miles (8 km) downstream of its position in this 2011 photo.

The outdated glacier boundaries and surface elevations from old maps have challenged scientists, too: lacking even the most basic information on the current extent of glaciers, Alaskan geologists and ecologists had no basis for inferring trends over time or the relationship of these trends to climatic changes. Modern tools like satellite imagery, laser altimetry, and high-accuracy differential GPS have enabled some academic and NPS researchers to accurately map modern glacier extents within the limited scope of individual research projects, but this work was initiated to address the outstanding need to comprehensively and consistently document glacier extent throughout the glaciated national park lands in Alaska (Figure 3).

Our project, which began in 2010 and is scheduled for completion in December 2013, relies primarily on existing data to assess glacier status and trends in three ways: 1) map glacier extents for all glaciers, 2) assess changes in glacier volume for a smaller subset of glaciers, and 3) write interpretive summaries of glacier change for 1-3 "focus glaciers" per park. The scope of the project is further summarized in Table 1; here, we present some preliminary results and discuss their implications.

Figure 1. The terminus of Brady Glacier, a focus glacier in Glacier Bay NP&P, has hardly moved in the last half-century. Note the large shoal developing downstream of the formerly tidewater margin, shown here in a 2006 oblique aerial photo.

Photograph courtesy of Denny Capps

A New Map of Glacier Extents

There is one obvious reason why all the glaciers in Alaska's parks had not been remapped since the mid-20th century. There are a lot of them. The precise number was until recently not even known, but our new map (Figure 3) includes 7012 distinct modern glaciers that are contained wholly or at least partly within the boundaries of nine Alaskan National Park units (Table 2). Those glaciers cover about 16873 mi^2 (43,700 km^2) of land, about half of the approximately 33938 mi^2 (87,900 km^2) of total ice coverage (including glaciers outside of the National Parks) in Alaska and neighboring Canada (Berthier et al. 2010).

As a glance at Figure 3 makes clear, the glaciers are not evenly distributed among the parks. The glacier heavyweight, by far, is Wrangell-St. Elias NPP. Nearly half of the Alaska Park glaciers are in WRST (Figure 4), but the ice coverage there is even more important when measured by total ice coverage: WRST accounts for 67% of all ice-covered area in the Alaska parks. Generally, Glacier Bay, Denali, and Lake Clark are the next most important parks in terms of glacier coverage, Katmai and Kenai Fjords contribute slightly less, and glaciers of Klondike Gold Rush, Aniakchak, and Gates of the Arctic are relatively minor, though what Gates of the Arctic lacks

Photograph courtesy of JT Thomas

Figure 2. University of Alaska researchers Michael West and Tim Bartholomaus prepare seismometers for deployment near the calving terminus of Yahtse Glacier in 2011. Modern visitors to this site in Wrangell-St. Elias National Park and Preserve shouldn't trust their maps. The USGS topographic map for this site was made in 1957, and shows this rocky beach under at least 175 meters of ice. The Yahtse Glacier terminus was over 5 miles (8 km) downstream of its present position at that time, and was over 25 miles (40 km) downstream in the late 1800s (Barclay et al. 2006).

in glacier area it makes up for partially in glacier number: the park actually has 178 glaciers—they're just all small.

The numbers just presented are based entirely on analysis of "modern" (2003-2010) satellite imagery (mostly Ikonos and Landsat). We often started with preliminary outlines from other sources, but then laboriously edited them manually, one mouse click at a time, on a computer screen. Accuracy of the process thus depends not only on judgment, but also on the resolution, cloud cover, time of year, and even time of day for a given image. But over time, satellites take many images, allowing us to select only the best ones to work from. Cartographers that created the USGS topographic maps upon which our "map date" inventory was based (Table 2 and Figure 4) had no such luxury, and were typically forced to judge glacier boundaries and elevations from a single aerial photo.

An example from Aniakchak NM&P exemplifies the challenge of comparing historic and modern datasets (Figure 5). High-quality satellite imagery clearly depicts crevassed glacier ice, a conclusion corroborated by Alaska Volcano Observatory scientists who have worked inside the caldera rim (Neal et al. 2001 and Figure 6). But was that ice present in 1957, when aerial photos used to make the topographic map were taken? Examining the comparatively low-resolution aerial photo taken early enough in the melt season to contain substantial remnant seasonal snowcover, the USGS cartographer reasonably enough decided no. But because the debris-mantled glacier ice seen in the caldera today could not conceivably have formed in just a few decades, we conclude that the original map (and hence, the "map date" portion of our inventory, which is an unedited digital archive of glaciers on the original USGS maps) is wrong.

The trend of increasing glacier numbers (Figure 4) may partly reflect the real subdivision of shrinking valley glaciers into multiple smaller tributaries, but we judge that trend mostly to phenomenon described above. The 7% decline in statewide glacier-covered area is probably a more robust reflection of real changes in the half-decade since most of the USGS maps were made (Figure 4). It is, in fact, a conservative estimate, since the modern figure includes the areas of many small glaciers that were mapped for the first time in satellite imagery. Loss of glacier cover is also a consistent trend, occurring to some extent or another in every park but Aniakchak, where the newly mapped caldera ice dominates the very small signal.

Zooming in on the Map

At the broad, statewide scale, there is a clear scientific consensus that warming temperatures are the primary factor driving the loss of glacier ice. But every glacier is different, and behind this generalization are many complications. We are using the focus glacier component of this project (Figure 7) to tell the stories of some of the diverse ways that glaciers respond not only to climate, but also to the landscape around them.

Our focus glaciers include, for example, several tidewater or recently-tidewater glaciers with highly variable trends in extent. Yahtse Glacier is one. It was discussed earlier for its dramatic retreat since 1957, but it has recently been advancing. Meanwhile, the terminus of Brady Glacier has been remarkably stable for the last several decades while slowly building an outwash plain (Figure 1). The fluctuations of these and other Alaskan tidewater glaciers represent different stages of the well-known tidewater glacier cycle—a process that is only indirectly tied to climate (Post et al. 2006).

Brady Glacier also highlights the importance of considering glacier thickness (and not just extent) when looking at glacier change over time. The Brady's stable terminus hides an ongoing and substantial "deflation" of the glacier surface that repeat laser altimetry measurements reveal. Measurements from 1995-2000 document an average annual loss of 0.12 mi^3 (0.5 km^3) ice volume (Figure 8). Similar results from 2000 to 2010 are not shown. Our final report will include comparable analyses for over 60 glaciers distributed through five of the Alaskan parks.

The Knife Creek Glacier, in Katmai NP&P, is a focus glacier that illustrates another interesting wrinkle: many of the glaciers in our study lie on or downwind of

Alaska's abundant volcanoes. On June 6 and 8, 1912, the world's largest volcanic eruption of the 20th century blanketed this glacier, and the surrounding landscape, in a thick layer of volcanic ash. Subsequent caldera collapse then added insult to injury, "beheading" the glacier by removing a substantial portion of its accumulation zone. With repeat photography (Figure 9) and other analyses we concur with earlier researchers (Muller and Coulter 1957) who concluded that the competing effects of these two phenomena—ash deposition reducing melt rates after removal of the glacier's upper elevations reduced accumulation—have combined to yield surprisingly little change in the overall size of this embattled glacier.

Other focus glaciers will provide us an opportunity to consider the unique qualities of surging

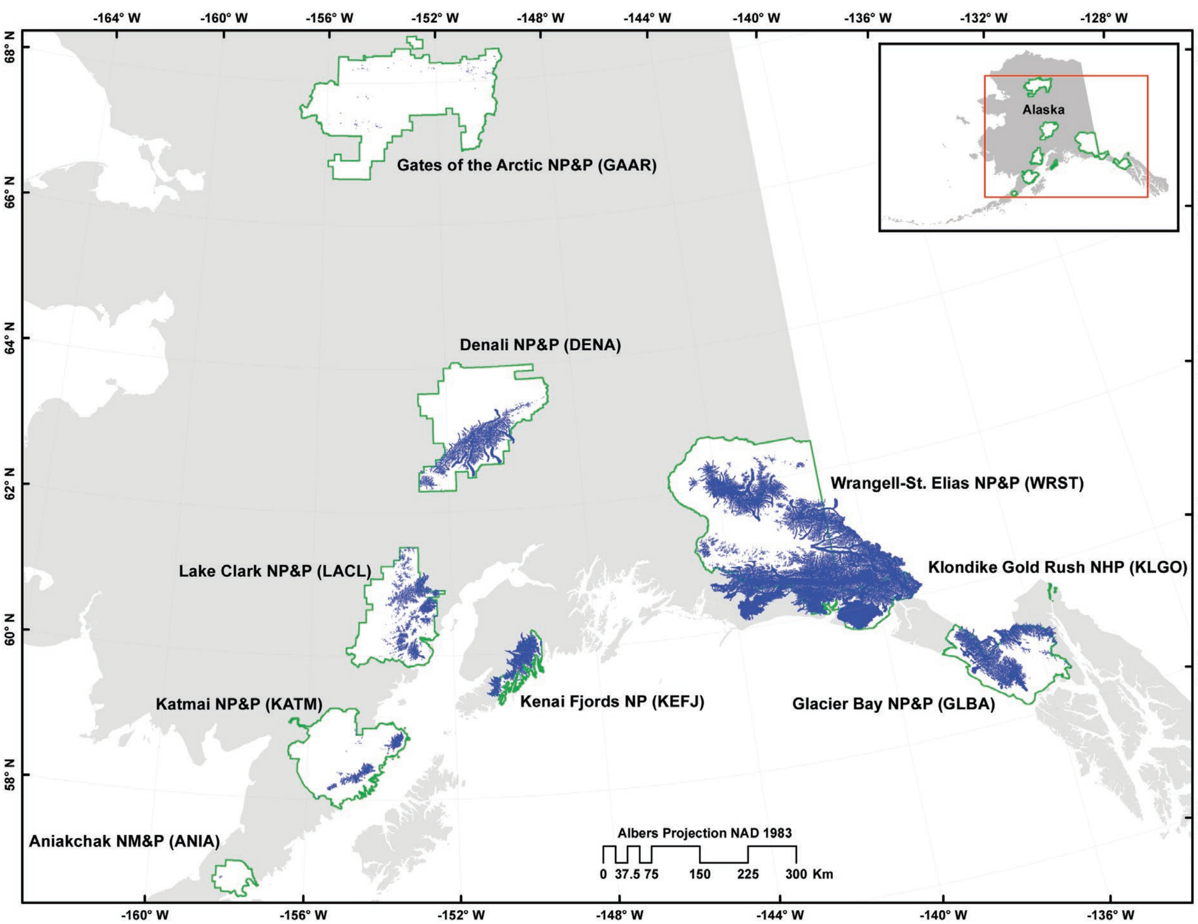

Figure 3. Nine national park units in Alaska contain glaciers. They are shown here with recently completed modern (between 2003 and 2010) map outlines of the >7000 glaciers partly or wholly contained within those park unit boundaries (blue polygons). At this scale, glacier outlines are barely visible in some places (e.g. Klondike Gold Rush), while in others (e.g. Wrangell-St. Elias) the massive glaciers spill well outside the park boundaries. Park labels include the following abbreviations: NP (National Park), NPP (National Park and Preserve), NHP (National Historic Park), and NMP (National Monument and Preserve). These and parenthetic four-letter abbreviations for each park will be used elsewhere in this article for brevity.

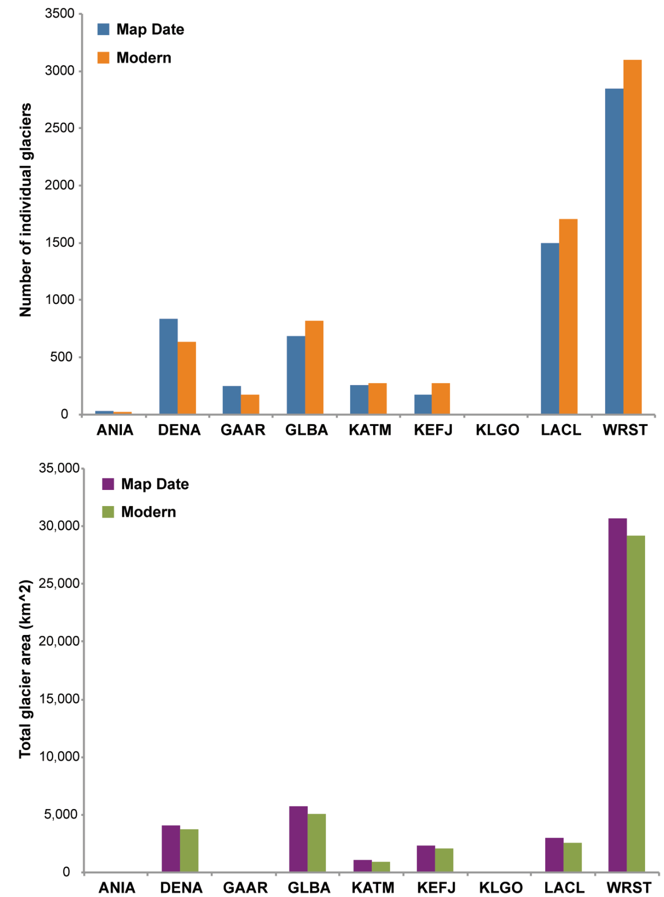

Figure 4. Numbers (above) and areal coverage (below) of modern and historic glaciers partly or wholly contained within nine national park units in Alaska. "Map Date" glaciers are based on USGS topographic maps, mostly dating to the 1950s and 1960s. "Modern" glaciers are based on satellite imagery collected between 2003 and 2010. See Figure 2 for park unit abbreviations.

Table 1. Summary of the status and trends project, including project objectives, scope of effort, data sources, and key personnel.

	Extent Mapping	Volume Change	Focus Glaciers
Project Objectives	Map modern (2003-2010) and historic (typically 1950s and 1960s) outlines of glaciers	Determine glacier surface elevation changes over recent decades with repeat laser altimetry	Summarize known history of glacier change and landscape response over all known timescales
Scope of Effort	All glaciers in all units, including some park-adjacent glaciers Map modern (2003-2010) and historic (typically 1950s and 1960s) outlines of glaciers	Existing coverage only: zero to <20 glaciers per park	1-3 glaciers per park
Data Sources	Modern glaciers: satellite imagery Historic glaciers: USGS topographic maps	Aircraft-mounted laser point data flown at quasi-decadal intervals on select glaciers	All available sources of data, ranging from historic photographs to modern research analyses
Key Personnel	Arendt and Rich (UAF)	Larsen and Murphy (UAF)	Loso (APU)

Table 2. Numbers of glaciers, and their summed areas (in km²), for nine individual glaciated national parks in Alaska.

Park Unit	Number (map date)	Number (modern)	Number (% change)	Area (map date)	Area (modern)	Area (% change)
ANIA	29	20	-31%	1.6	1.8	16%
DENA	836	631	-25%	1,559.2	1,442.2	-7%
GAAR	253	178	-30%	36.9	20.8	-44%
GLBA	682	820	20%	2,217.8	1,974.5	-11%
KATM	255	278	9%	410.7	353.2	-14%
KEFJ	177	275	55%	898.2	803.0	-11%
KLGO	2	1	-50%	2.0	0.5	-74%
LACL	1501	1707	14%	1,141.1	1,005.3	-12%
WRST	2843	3102	9%	11,847.4	11,276.6	-5%
All	6578	7012	7%	18,114.9	16,878.0	-7%

glaciers, small debris-covered cirque glaciers, a massive icefield, ice and moraine-dammed lakes, and a massive icefield (Figure 7). Our goal is neither to be comprehensive nor representative, but rather to highlight the diversity of glacier types and behaviors, and to consider anecdotally the consequences of these behaviors for the ecology, hydrology, geomorphology, and human geography of the landscapes they inhabit.

Conclusions

With respect to climate change, glaciers have been called "the canary in the coal mine." The implication—that by watching the glaciers we can more easily infer the more subtle changes occurring in our climate system—depends on somebody actually watching the canary. In our case, that means a regular, systematic, and comprehensive program of glacier monitoring. With this project, NPS has taken a major step towards accomplishing that goal.

The final results of our work will be presented in two products. A Natural Resource Technical Report will document data sources, methodology, and results;

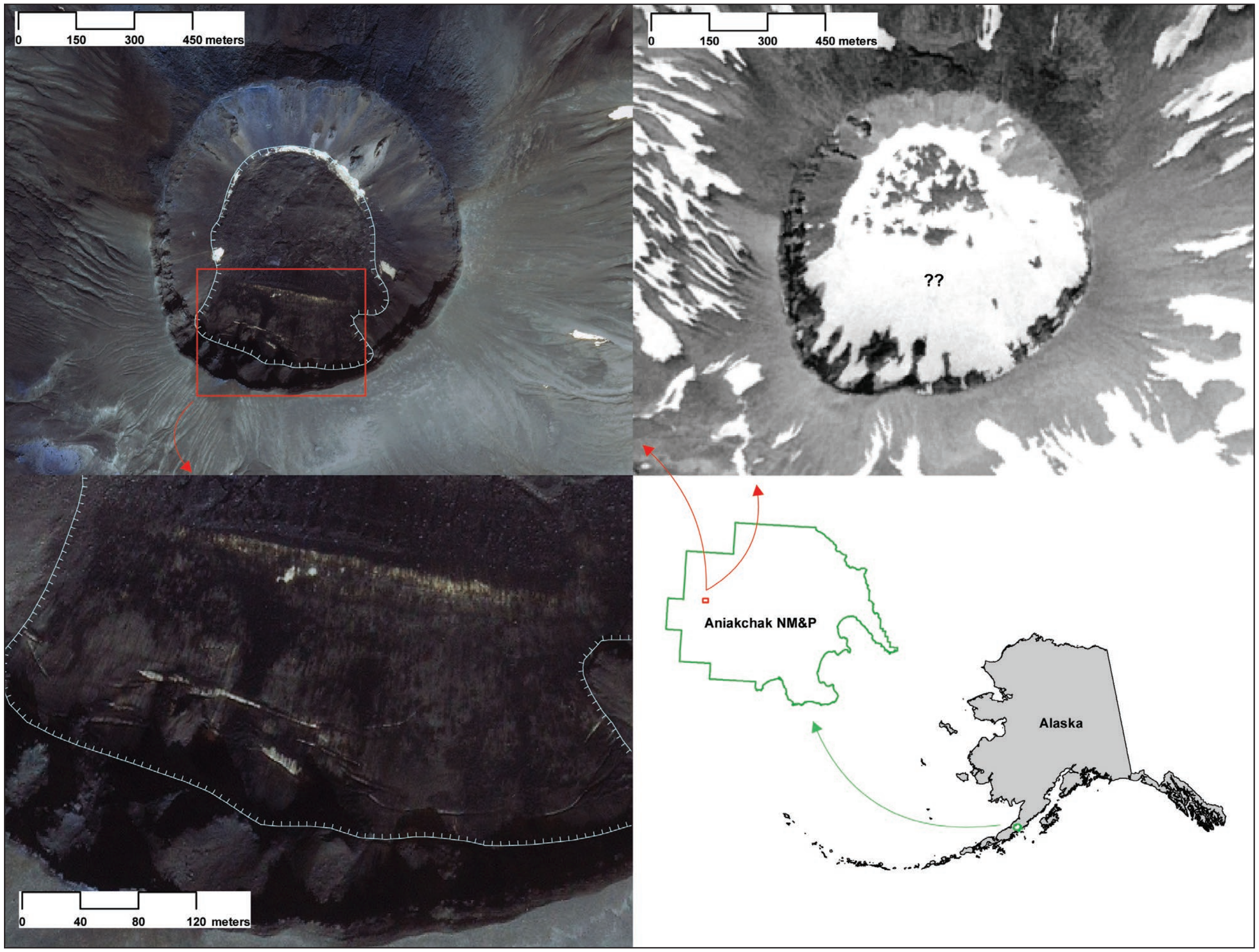

Figure 5. Comparison of base imagery used for mapping glacier outlines in Aniakchak Caldera, in Aniakchak NM&P. The USGS topographic map for this region was based on a 1957 aerial photo shown at upper right. The cartographer saw (and mapped) no glaciers. The modern Ikonos satellite image at upper left, and shown in greater detail at lower left, clearly reveals crevasses that help distinguish a debris-covered glacier surface outlined in blue.

Figure 6. Detail of the inner Aniakchak Caldera from a September 9, 2011 photo by Game McGimsey of the Alaska Volcano Observatory. The stream in center foreground is emerging from debris-covered glacier ice.

analyze those results; and discuss the implications of those analyses. It will be accompanied by a permanent electronic archive of geographic and statistical data and is intended to serve a specialized audience interested in working directly with the project's datasets. An interpretive report will be a non-technical document suitable for glaciologists, park interpretation specialists, park managers, and park visitors with no particular background in science or glaciology. The document will be comprehensive and thorough, however, and is envisioned as graphics and photo-intensive, content rich, and accessibly written. Content will include a comprehensive literature review, detailed summaries of the key findings of the technical report, and the focus glaciers narratives.

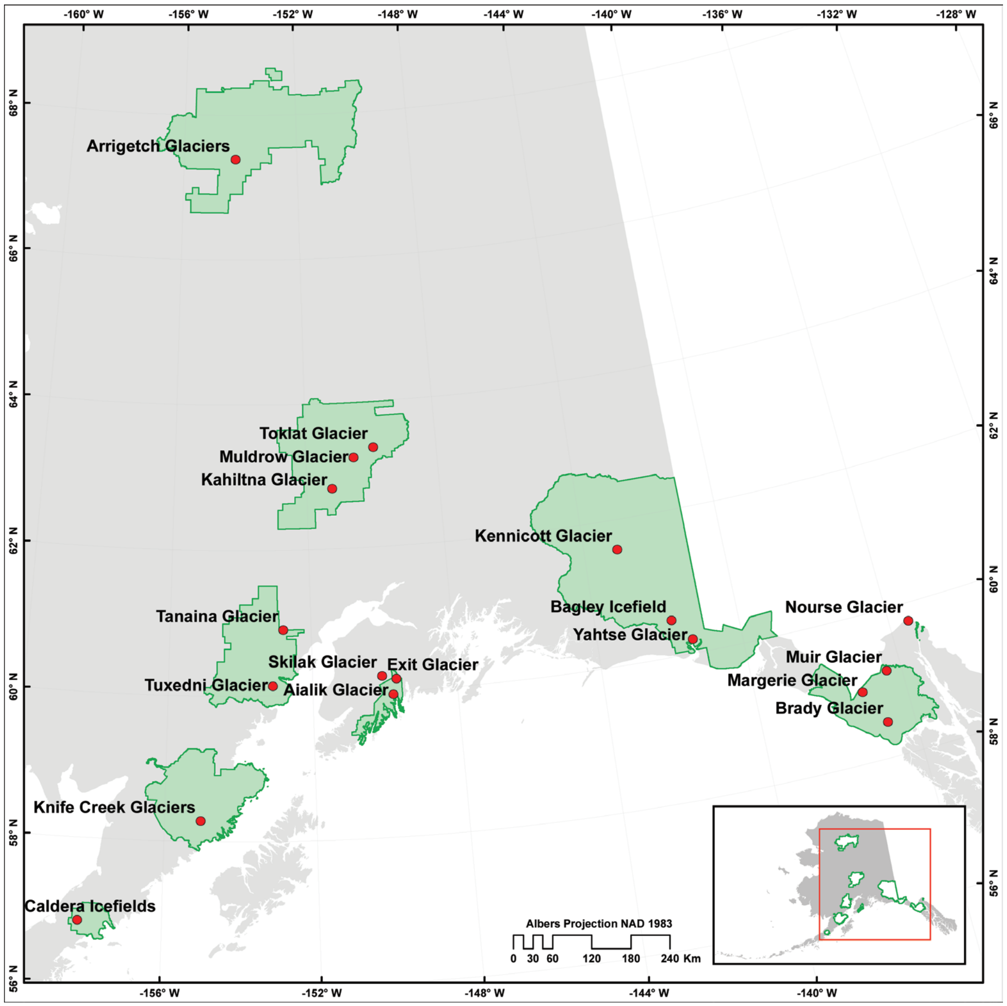

Figure 7. Eighteen focus glaciers selected for a more detailed, narrative-style description in the final Status and Trends report.

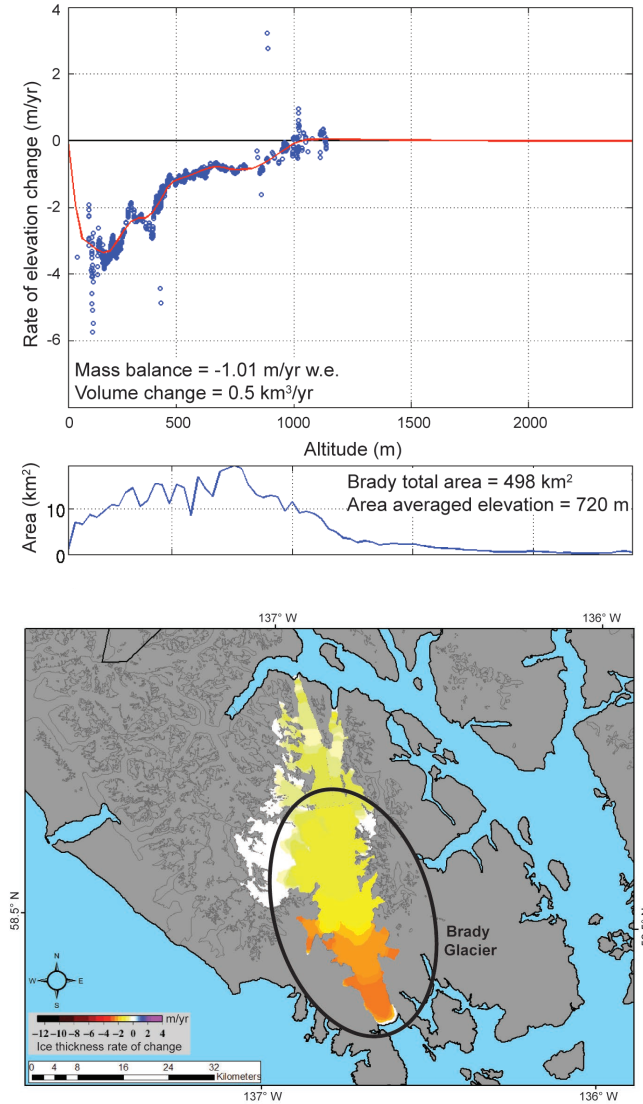

Figure 8. Changes in glacier volume for Brady Glacier, GLBA, between 1995 and 2000. Upper panel: blue dots estimate annual rates of surface elevation change for different glacier elevations based on repeat laser altimetry measurements. When combined with the hypsometry of the glacier, these predict an average annual loss of 0.12 mi³ (0.5 km³) glacier ice. Lower panel: map view of surface elevation changes.

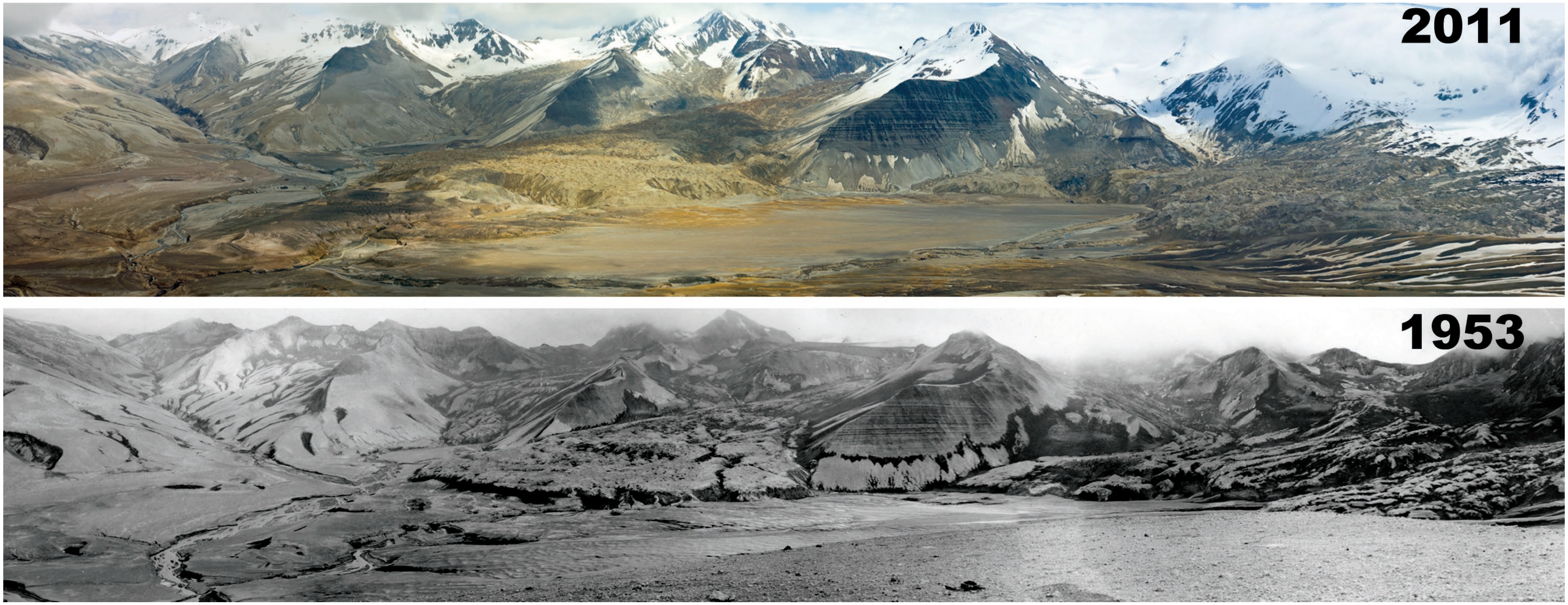

Figure 9. Repeat photographs of the Knife Creek Glacier showing it on 15 June 2011 (above) and 6 July 1953 (below). Photos taken from approximately 3700' (1,100m) on the eastern summit of Broken Mountain, Valley of Ten Thousand Smokes. Snow appears black in the older image. Photos: JT Thomas (upper) and E.H. Muller (lower).

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Assessing the Effects of Changing Climate on the Kahiltna Glacier using Field, Airborne, and Satellite Observations

By Joanna Young and Dr. Anthony Arendt

The Kahiltna Glacier in Denali National Park and Preserve (DNPP) (Figure 1) is best known to mountain climbers as a starting point when summiting Mt. McKinley, the highest peak in North America. Visitors on flightseeing tours are fascinated by its classic moraine stripes and dramatic icefalls. To scientists, however, the Kahiltna Glacier represents a prime opportunity to examine the effects of a warming climate on Alaska glaciers.

In 1991, the National Park Service partnered with researchers to establish a monitoring program on the Kahiltna Glacier which provided valuable long-term data, albeit from a single location. To better represent the vast extent of the glacier, we expanded observations during 2010 and 2011, and supplemented with newly-available airborne and satellite data that will allow us to monitor regions of the glacier inaccessible by conventional field methods. The goal of our work is to determine the mass balance—or mass change—of the Kahiltna Glacier over the past several decades, comparing four of the leading mass balance methods used by glaciologists.

Study location

The Alaska Range forms a sweeping topographic barrier to moist weather systems entering inland off the Gulf of Alaska; glaciers on the south side of the range receive more snowfall and grow significantly larger than those on the north side. The Kahiltna Glacier flows southward from the summit of Mt. McKinley, at an altitude of 20,013 ft (6,100 m), to just 886 ft (270 m) above sea level at its terminus. This elevation range is thought to be the greatest of any glacier on Earth. Covering nearly 200 square miles (500 km^2) with a centerline length of 44 miles (70 km), the Kahiltna Glacier is the largest glacier within the park. Together, these two characteristics—a large size and broad range of elevations—present challenges to field logistics and invite innovative approaches to integrating data from other sources.

Figure 1.

Motivation

Glaciers throughout the world have been experiencing increasing rates of mass loss over the last several decades (AMAP 2010). Together, glaciers of Alaska and Canada are one of the largest contributors to changes in Earth's ocean volume, causing about 0.006 inches/year (0.14 mm/year) of sea level rise (Gardner et al. 2013). Understanding the hydrochemistry of melting glaciers is important for several reasons. First, glaciers act as vast freshwater reservoirs, prompting research into the timing and quantity of runoff that will occur as they continue to lose volume in warming temperatures. Also, a catchment's concentration of dissolved minerals, organic compounds, and pollutants changes as meltwater patterns change, impacting water quality for downstream ecosystems as well as for human consumption and irrigation. Finally, from an outreach perspective, the rapid disappearance of glaciers has sparked interest in the broader community affording scientists, resource managers, and interpreters the opportunity to use data to engage in an active dialogue with the public about climate and environmental change.

Related Research

The National Park Service (NPS) initiated a measurement program on the Kahiltna Glacier in 1991, working with Lawrence Mayo (U.S. Geological Survey) and Dr. Keith Echelmeyer (University of Alaska Fairbanks). These researchers established a single long-term monitoring site, where NPS glaciologists continue to make biannual measurements (Figure 2). Park scientists also recently collaborated with University of Alaska Fairbanks glaciologists to examine glacier area change within DNPP, where they observed an overall pattern of glacier retreat (Burrows et al. 2011). Our work leverages and expands on these studies, quantifying glacier-wide mass losses and examining multiple time periods.

Other studies have also provided information about the flow dynamics of the Kahiltna Glacier. Researchers at Alaska Pacific University have worked to constrain the timing of re-emergence of human waste deposited along the well-traveled West Buttress climbing route on Mt. McKinley, and to evaluate potential effects on downstream water quality (Goodwin et al. 2012). Near-surface radar has recently revealed different thermal zones in the glacier, providing information that can help constrain future mass change projections (Gusmeroli et al. 2013). Ground-penetrating radar studies have also been conducted, with the goal of locating an ice core site for reconstructing climate trends during the last few centuries (Campbell et al. 2012). Collaborations with these research groups have been helpful for sharing data and logistics, and for broadly exploring the changing face of the Kahiltna Glacier.

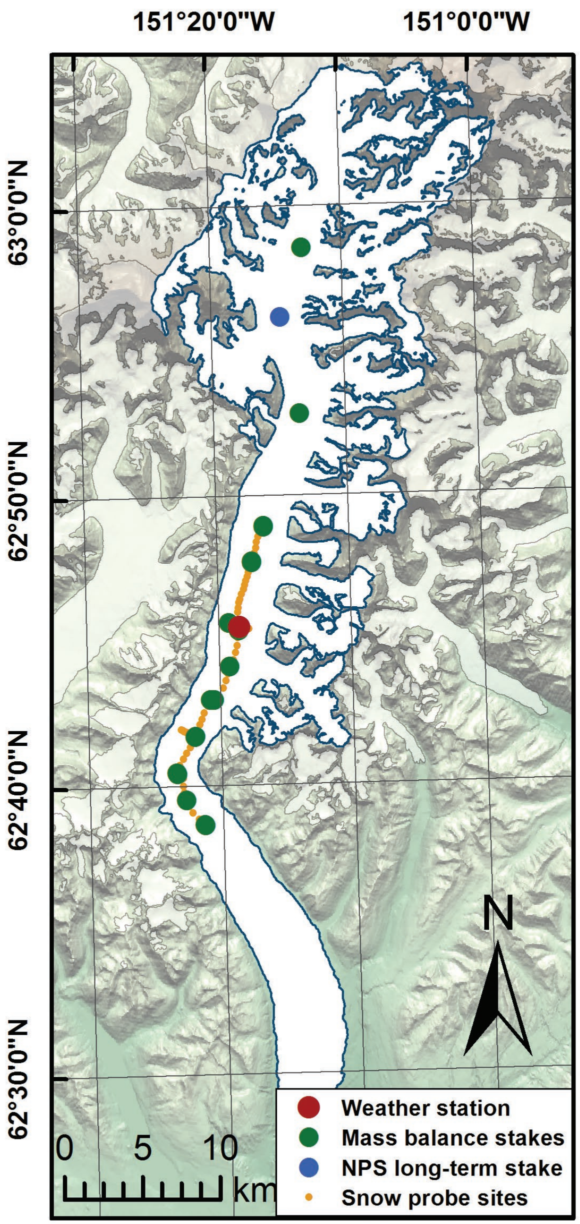


Figure 2. Locations of ground measurements carried out in 2010 and 2011 on the Kahiltna Glacier (catchment outlined in blue). Mass balance stake locations are shown in green, the long-term National Park Service site is in blue, snow depth measurements are in orange, and the site of our automated weather stations is in red.

Figure 3. Installation of a mass balance stake.

Methods for estimating mass balance

Glaciers are defined by two main characteristics. First, they are composed of snow that persists for longer than one year. As the snow accumulates year after year, it compresses under overlying snow to eventually form glacier ice. This accumulation process is the primary means by which mass is added to a glacier. Second, glaciers flow downhill, giving rise to the description of glaciers as "rivers of ice." As it is transported from high mountains to lower elevations, the ice encounters warmer air temperatures and experiences summer melt. This surface melting—or ablation—is the main process by which a land-terminating glacier like the Kahiltna loses mass. Altogether, a glacier's mass change or mass balance is defined as the difference between annual accumulation and ablation.

Traditionally, glaciologists have measured mass change through simple methods. Mass balance stakes are installed vertically into the ice at the beginning of summer and visited later to measure surface lowering (Figure 3). Accumulation is measured by digging snow pits and sampling snow density, yielding the total water content of the snowpack. This is the method used by NPS glaciologists on the Kahiltna Glacier. The four methods below describe how scientists use melt models, airborne data, and satellite technologies to estimate mass changes for the entire glacier.

1. Melt modeling

Melt modeling is a computational approach that relies on field observations of air temperature for input, and accumulation and ablation at mass balance stakes for calibration. Several field campaigns were carried out on the Kahiltna Glacier in 2010 and 2011. We installed 11 stakes and five temperature sensors at different elevations, and two weather stations to monitor local conditions (Figure 4). The winter snowpack was characterized by snow depth and density measurements, supplemented with data from nearby weather stations.

We then use a melt model (Hock 1999) to derive a relationship between air temperature and melt. The model determines mass balance at every point on the glacier, based on elevation gradients of air temperature, melt, and snowfall. We use our 2010 and 2011 ground measurements for input and calibration, and apply the model retroactively for 20 years using a past climate data product and the NPS mass balance record. We calculate an average balance of -5.97 +/- 3.77 feet water equivalent per year (ft we/yr) (-1.82 +/- 1.15 m we/yr) for the period 1992-2011 (Figure 5).

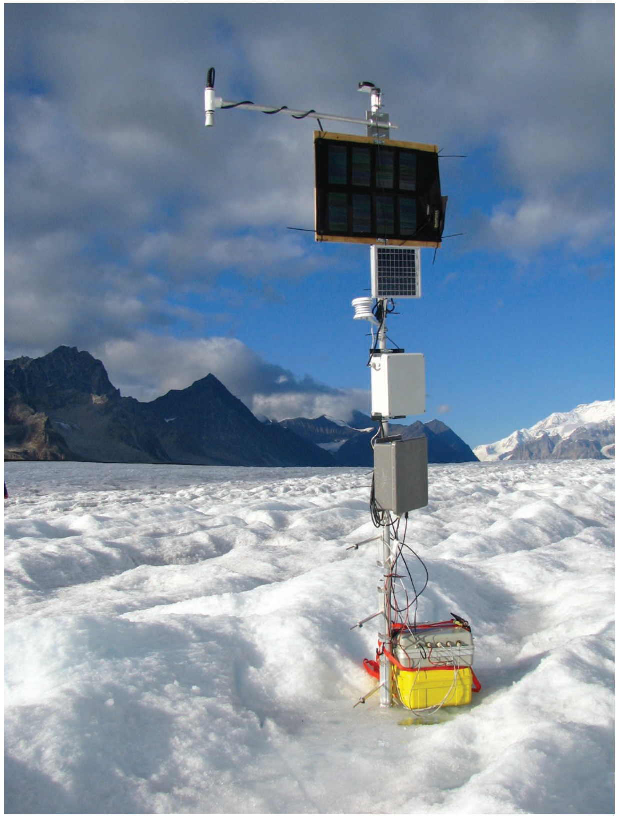


Figure 4.

2. DEM differencing

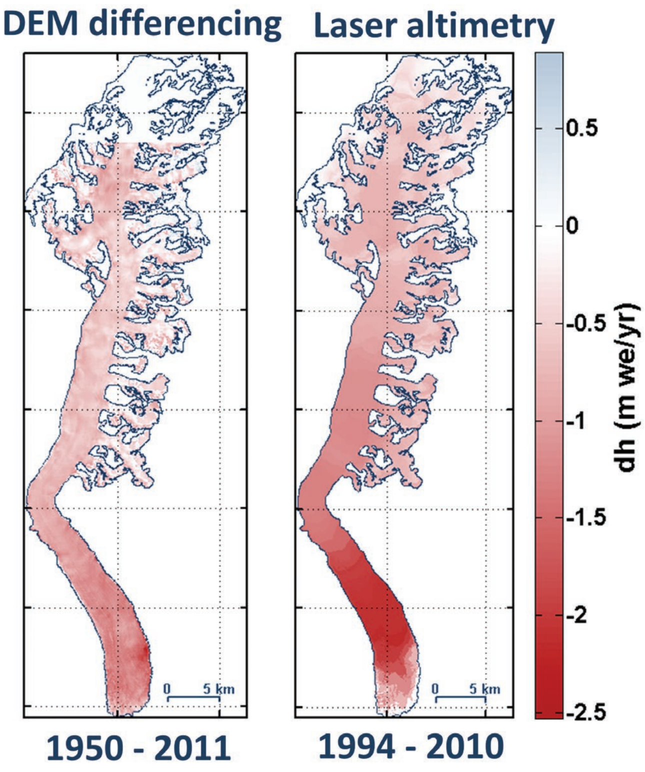
In this method, multiple digital elevation models (i.e. DEMs, or maps of elevations at every point on the glacier) from different time periods are compared to determine how the glacier surface has evolved. For the Kahiltna Glacier, we start with a DEM derived from U.S. Geological Survey maps based on aerial photographs from about 1950, and compare this to a 2011 DEM based on airborne radar observations (http://www.gina.alaska.edu/).

The resulting difference map shows the glacier surface changes that occurred between the early 1950s and 2011 (Figure 5). The map reveals thinning over 92% of the area for which data is available (note: the northernmost region has limited satellite imagery). Averaged over the full glacier, we obtain an annual mass change of -1.51 +/- 0.46 ft we/yr (-0.46 +/- 0.14 m we/yr).

3. Laser altimetry

Glacier surface height changes can also be measured via repeat airborne laser altimetry, a technique carried out by University of Alaska Fairbanks glaciologists since 1993 (Johnson et al. 2013). Mounted in a small airplane, the system is composed of a high-accuracy Global Positioning System (GPS) receiver, a laser rangefinder, and a gyroscope. The GPS records the position of the plane as it flies down a glacier centerline, the laser continuously measures the distance between the plane and the ice surface, and the gyroscope measures the laser's pointing direction. From these, centerline surface elevation profiles are created. Repeating the flights every few years allows scientists to compare profiles over time, and to extrapolate the changes to the entire glacier.

Figure 6 (see 1994-2010 graphic) shows surface height differences determined between 1994 and 2010. We find significant thinning at all elevations measured (note: the highest elevations were not sampled). Averaged over the entire surface, the annual balance is -2.46 +/- 0.33 ft we/yr (-0.75 +/- 0.10 m we/yr). Estimates have also been generated for different time periods: from the 1950s to 1994, by comparison to the 1950s DEM described earlier, we find -1.51 +/- 0.36 ft we/yr (-0.46 +/- 0.11 m we/yr), and for 2008-2010, we find -3.25 +/- 1.51 ft we/yr (-0.99 +/- 0.46 m we/yr).



Figures 5 and 6. Digital elevation model (DEM) difference map showing surface height changes on the Kahiltna Glacier between the early 1950s and 2011. The 1950s DEM was generated using aerial photographs, and the 2011 DEM was based on airborne radar observations (note: the upper region lacks data due to limited satellite imagery). Map units are in meters of water equivalent per year.

4. GRACE gravimetry

Glacier mass balance can also be estimated using data from the National Aeronautics and Space Administration (NASA) Gravity Recovery and Climate Experiment (GRACE). These twin satellites orbit one behind the other, equipped with a high-precision ranging system that detects miniscule changes in the distance between them. As the first satellite passes over a denser land mass, it is pulled slightly ahead. Scientists use these changes in distance to construct monthly maps of the Earth's gravity field, which are then separated into groundwater movement, atmospheric changes, and glacier mass changes. Zooming into one ice-covered region, like DNPP, scientists can construct a time series of mass changes that have occurred therein (Figure 7).

Scaling these results to the Kahiltna Glacier, we calculate an average mass balance between 2003-2010 of -1.18 +/- 0.36 feet we/yr (-0.36 +/-0.11 m we/yr).

Discussion

Mass losses are revealed by each of four techniques for every observation period from the 1950s to today. (Figure 8). We see strong agreement between early laser altimetry estimates and DEM differencing. We also see evidence for melt acceleration towards the late 1990s/ early 2000s, agreeing with other findings as it occurred concurrently with a 1.4F (0.8oC) increase in average summer temperatures recorded near DNPP (Arendt et al. 2009). We find, however, that the preliminary melt model estimate seems to overestimate mass losses and has greater error than the other techniques. This is likely due to the sparse ground data available, and attests to the challenges of obtaining sufficient field measurements for a large, remote glacier. Further analyses may help refine this estimate and associated error. Ultimately, our study confirms the importance of comparing multiple techniques to constrain mass changes, and points to airborne- and satellite-based methods for obtaining data for previously inaccessible glacier regions.

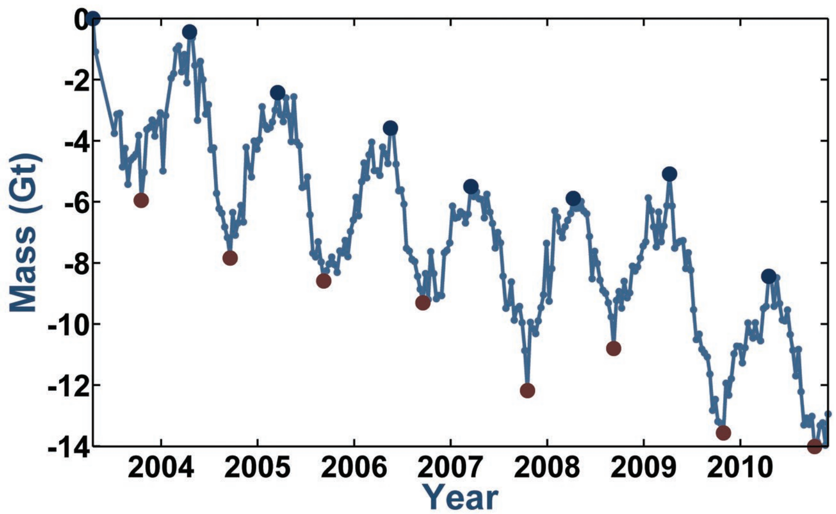


Figure 7. Time series of glacier mass change observed by GRACE satellites for Denali National Park since 2003. Mass change in gigatons (Gt) is expressed relative to the first date of observations. End-of-winter maxima, after snow accumulation, are indicated in dark blue; end-of-summer minima, after summer melt, are shown in red. The annual mass balance for the region is taken as the difference between subsequent minima, and this value is then scaled to the Kahiltna Glacier alone.

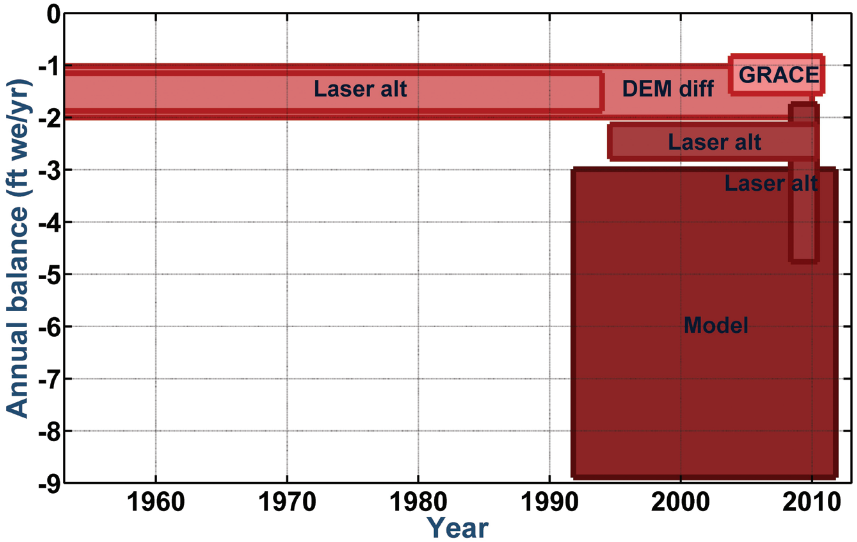


Figure 8. Mass losses are revealed by each of four techniques for every observation period from the 1950s to today.

Conclusions

Our study finds that the Kahiltna Glacier, the largest river of ice in Denali National Park and Preserve, is losing mass and becoming thinner. Scientists agree that the mass losses seen in glaciers of Alaska and the world are a result of increasing air temperatures over the past several decades. These losses are, at the local scale, affecting downstream freshwater supply; at the broader scale, they contribute to sea level rise. Despite being fed by significant snowfall from the highest peak in North America, the Kahiltna Glacier has been losing mass in warming temperatures, leading to gradual but visible changes in the Denali National Park landscape.

Acknowledgments

The authors acknowledge Dr. Regine Hock for melt modeling guidance, Dr. Chris Larsen, Dr. Nathaniel Murphy and Lee Zirnheld for laser altimetry estimates, and Sam Herreid for contributions to figures, all of the University of Alaska, Fairbanks. We also thank Rob Burrows and Guy Adema (National Park Service) for field assistance and Dr. Michael Loso (Alaska Pacific University) for ongoing collaboration. Funding was provided by the George Melendez Wright Climate Change Fellowship, the Center for Global Change, the Cooperative Institute for Alaska Research, the North Pacific Research Board, and NASA's Cryospheric Sciences program (grant NNH07ZDA001N-CRYO).

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TRUST ME
I'm an engineer
Wachusett Inlet
Muir Inlet
Adams Inlet
Lynn Canal
Endicott Gap
West Arm
Johns Hopkins Inlet
Reid Inlet
Tlingit Point
Sturgess Island
Beartrack Valley
Francis Island
Beartrack Cove
Whidbey Passage
Glacier Bay National Park Boundary
Geike Inlet
Willoughby Island
Strawberry Is
Chilkat Peninsula
Beardslees
Kidney Is
Lester Is.
Berg Bay
Gustavus
Rush Point
Bartlett Cove
Point Gustavus
Point Carolus
Dundas Bay
Alaska
Glacier Bay
Gulf of Alaska
Point Adolphus
Icy Strait
Hoonah
Chichagof Island
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0 4.5 9 18 27 36

Tracking Glacial Landscapes: High School Science Gets Real

By Cathy L. Connor, Clay Good, Riley Woodford, and Michael L. Hekkers

Introduction

The Gulf of Alaska's rugged Pacific seacoast is characterized by extreme topographic relief that has been sculpted by glacier erosion in a rapidly uplifting landscape. Along this tectonically deforming plate margin, Alaska's changing climate, powered by solar energy, drives the intense geochemical and mechanical weathering that disintegrates the rapidly uplifting bedrock. Deep geothermally-driven crustal dynamics along the Juan de Fuca spreading ridge far to the south ultimately results in extreme deformation along the shorelines of Glacier Bay National Park and Preserve. Over geologic timescales these tectonic forces deliver fresh rock to the surface, where it has been elevated into extreme topography like the 15,325' (4,671 m) Mt. Fairweather located only 12 mi (20 km) from the sea. Training young Alaskans to observe as well as to understand how these earth processes have left their record in local landscapes, can inspire lifelong learning interests in the sciences (Whitmeyer et al. 2009).

For four summers, between 2008 and 2011, the Alaska Summer Research Academy (ASRA) at University Alaska Fairbanks and the Design Discover Research (DDR) program at University Alaska Southeast provided authentic field experiences in Glacier Bay National Park in northern Southeast Alaska for homegrown high school students.

Figure 1. University of Alaska faculty, science educators, and high school students from around Alaska came together in the Alaska Summer Research Academy at Glacier Bay National Park and Preserve.

Photo courtesy of Diana Rapper.

Figure 2. (Map) Locations in Glacier Bay National Park in northern southeast Alaska.

Getting students to the landscapes -- Logistics

Glacier Bay National Park and Preserve lies on the mainland of the generally roadless Alexander Archipelago that is northern southeast Alaska. Inter-island and island-to-mainland access is made possible by the Alaska Marine Highway System (AMHS) ferries, private marine vessels, and small planes. Prior to 2011, access to this park from the state capital in Juneau only 80 miles away, was limited to expensive private boats, airplanes, or a challenging and time consuming kayak crossing of the wide fjords of Lynn Canal or Icy Strait.

Beginning in 2008, University of Alaska faculty teamed with science educators linked through a grant to the Juneau Economic Development Council's Springboard Program to create unique field science opportunities in Glacier Bay National Park for Alaska High school students (Connor et al. 2011). Initially the 60 ft (18 m) MV Glacier Seal served as our research vessel and floating field camp, transporting students from Juneau into Glacier Bay and back.

With the initiation of AMHS ferry service from Juneau to Gustavus in 2011, students brought bicycles onto the ferry and pedaled and hiked around on the large glacier outwash plain of Gustavus, just south of the National Park. They also traveled north over the Little Ice Age terminal moraine to GBNP headquarters in Bartlett Cove and accessed the upper bay by sea kayaks and tour boat shuttles. Students visited the bay's active tidewater glaciers in the Reid Inlet, Johns Hopkins Fjord, and the Tarr Inlet area of the West Arm of the bay as well as the deglaciated landscapes of Muir and Adams Inlet on the eastern side of the park (Figure 2).

Over the 4 years of these summer science field experiences our Alaskan students hailed from all over the state including Kotzebue, Chuathbaluk, Fairbanks, Seward, Soldotna, Palmer, Wasilla, Anchorage, Petersburg, and Juneau. A few out-of-state students travelled to Alaska from Massachusetts, Minnesota, Illinois, Colorado, Texas, and California to participate.

Landscape Change

The authors served as a multi-disciplinary cadre of instructors who provided academic content, field support, and onsite mentoring for the students each summer to unpack the complicated glacial story of this national park. The National Park Service provided us with an excellent naturalist who accompanied us and provided local insight. The students were introduced to the scientific disciplines of glaciology, glacial geology, plate tectonics, plant succession, wildlife biology, ornithology, and disturbance ecology as well as the social sciences, specifically anthropology and its subdiscipline of ethnohistory. During onboard seminars and on-the-ground immersion into the park's landscapes, students deployed marine instruments, surveyed plant and animal populations, and assessed the stratigraphic record. The faculty helped them assemble and interpret the key bits of information that they collected from each disciplinary area into a composite view of this region and to under-

Figure 3. Gathering Ice for Ship refrigeration

Figure 4. In Tidal Inlet on the Glacier Seal—learning about landslide geomorphology

Figure 5. Learning navigation and mariner skills as part of the field science experience.

stand the longer time scale natural history of a changing landscape through cycles of glacier advance and calving retreat. The climatic impacts to the lives of sixteenth century HUNA Tlingit teenagers, who were forced by rapidly advancing glaciers to flee their homeland and to seek refuge across Icy Strait in Hoonah, were recanted to our 21st century teenagers through readings of published oral histories (Dauenhauer and Dauenhauer 1987).

Glacier Bay -- The HUNA Tlingit Homeland

The indigenous people of northern southeast Alaska, the HUNA Tlingit, named their Glacier Bay Area homeland S'é Shuyee, "area at the end of the glacial silt" (HIA 2007). They identified their homeland as glacio-fluvial in nature, down to the grain size of the sediment. One of their important village sites was called L'eiwshaa Shakee Ann, "town on top of the sand mountain (dune)" and it existed between Point Gustavus and the Bear Track Mountains (HIA 2006), an area now inundated by the sea (Connor et al. 2009, Figure 6).

This very large terrestrial glacier outwash plain or glacier forefield was the existing landscape during this Neoglacial through Little Ice Age (LIA) period (5,000 years ago to ~1740 AD) of their residence time. The tall dunes or moraines could have provided leeward-side protection from the northerly katabatic winds blowing off the glacier, said to be far up the valley (Susie James in: Dauenauer and Dauenauer 1987). On the west side of the valley, in the present Berg Bay, the Chookanheeni clan members describe a meadow-lined river with clan houses of upstream and downstream family groups (Lily White personal communication with Wayne Howell NPS 2003).

Between 1724-1794, the up-valley glacier ice had advanced to the south over all of the Tlingit habitations in the lower-valley, and their surrounding outwash plain forests. This forced a mass human evacuation to Hoonah (Glacier Bay Story Susie James, in Dauenhauer and Dauenhauer 1987) across Icy Strait. The ice advance also erased the physical archeological record in the lower bay region, leaving oral histories an important source of data for landscape reconstruction (Figure 7).

By the time of arrival of the English explorer George Vancouver in 1794 with his cartographers, naturalists and scientists, the glacier, which had earlier extended beyond the present bay entrance, had begun a calving retreat. Master of the HMS Discovery, Joseph Whidbey, recounted grappling with a mass of ice bergs in Icy Strait and near the then glacier terminus at the newly exhumed Bartlett Cove, present site of Park Headquarter (Lamb 1984). When John Muir arrived 85 years later in 1879, the ice terminus positions had retreated to Tlingit Point (~24 mi (38km) NW of Bartlett Cove), and the glacier had retreated and separated into its tributary branches spanning the West Arm and Muir Inlet, opening up lower central Glacier Bay to marine waters (Burroughs and Muir 1899, Figure 8).

Since that time, the once coalesced ice mass has retreat 60 mi (100 km) up the bay, subdividing into even more glacier tributaries (Molnia 2006). The post-LIA landscape has uplifted 20' (6 m) over the past ~200 years relative to sea level, with some sites pulsing upward at rates of 10" (25 cm)/yr (Larsen et al. 2005). Gustavus resident, Morgan DeBoer owns land north of the ferry dock, settled by his family 50 years ago when it was flooded by daily tides. Since then, his emergent nine hole golf course has the 21st century potential for further expansion with continued uplift of the shoreline along Icy Strait (Figure 9).

Observing Landscape Change over Century Timescales

The Little Ice Age terminal moraine separates Park Headquarters in Bartlett Cove from the broad outwash

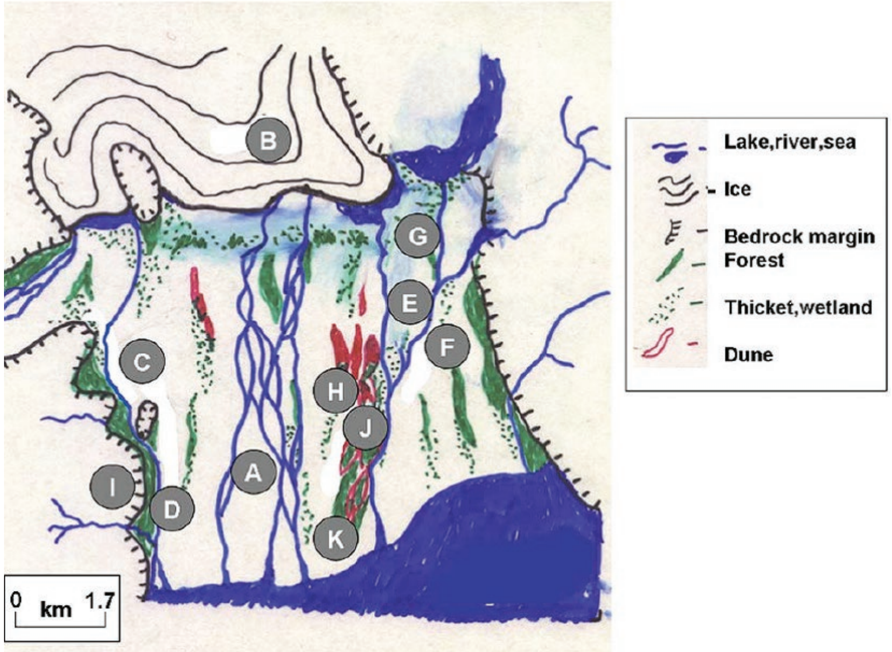
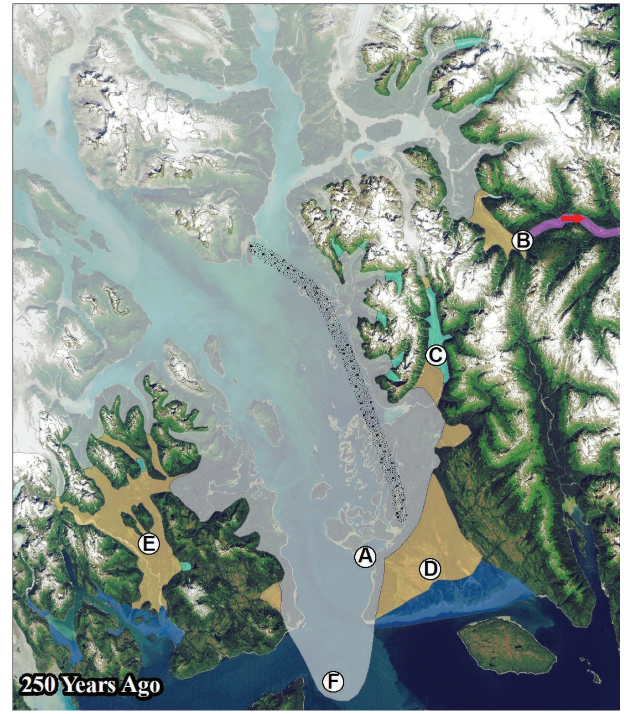


Figure 6. (Left) Tlingit LIA Remembered Landscape—Now represented by the glacially dissected Beardslee Formation.

A. Area at the end of the Glacial Silt, B. Little Black Glacier, C. Grassy River, D. Tributary to Grassy river, E. Sockeye Salmon River, F. Big Sockeye Salmon River, G. Among the Little Lakes, H. Sand Mountain, I. Black Cliff, J. Town on Top of the Glacial Sand Dunes, K. Clay Point (Connor et al. 2009).

Figure 7. (Right) A. Deflection of LIA Terminus in Bartlett Cove, B. Endicott Gap and Glacial Lake Outflow into Lynn Canal, C. Ice marginal lake Bear Track, D. LIA Gustavus glacial outwash fan complex, E. Glacial outwash in the Dundas Basin, F. Terminal Position LIA Glacier Advance into Icy Strait (Connor et al. 2009).



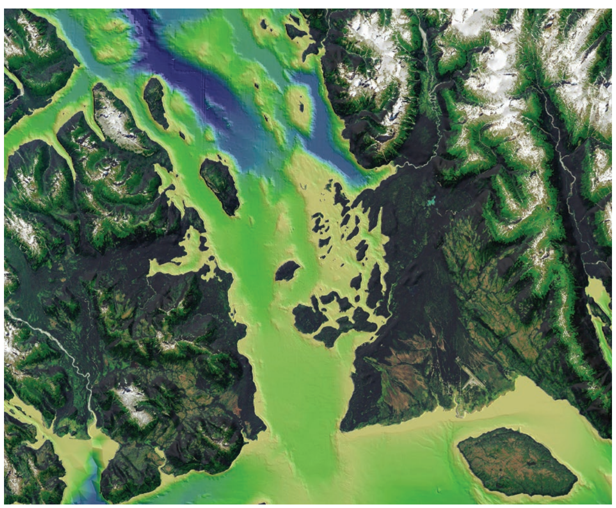


Figure 8. Bathymetric map of lower Glacier Bay shows dissected Little Ice Age outwash plain and former HUNA Tlingit homeland now represented by the Beardslee Formation. From MODIS image 2004.

Figure 9. Uplifting tidal flats along the Gustavus foreland. View is to the west along Icy Strait with Lemesuier Island and the entrance to Glacier Bay.

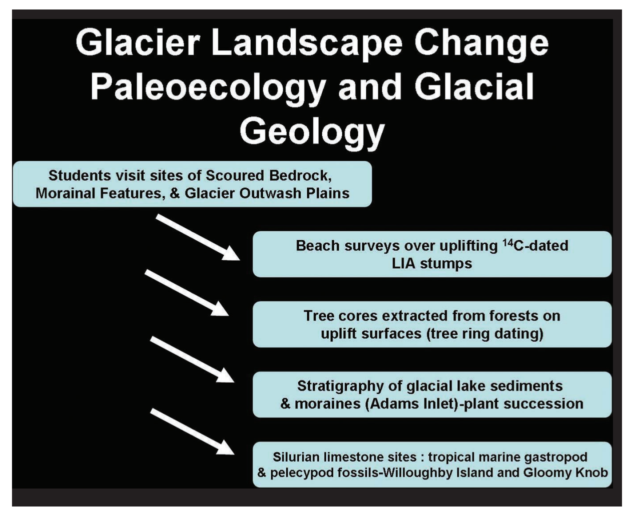


Figure 10. Student data-collection types for access to understanding of active landscape change.

plain that underlies Gustavus and its airport. Hikes along Dude Creek (Figure 17), the Good and Salmon Rivers, and Glen's Ditch Road and the Nature Conservancy's Nagoonberry Trail east of the airport, enabled students to observe incision points into emergent subtidal sediments (Figure 12). Creek channels featured uplifted intertidal and subtidal marine sediments overlain by young stream deposits. These glacier forefield sites also provided excellent access to areas of active plant succession, and provided opportunities to observe the habitat and behavior of wolves, cranes, moose, bears, and marine waterfowl in this dynamic seacoast habitat along Icy Strait. Students conducted beach surveys to measure gradients (Figure 11, 18, 19, 21, and 25) and cored young spruce trees growing on glacial moraines and uplifting shorelines to obtain ages and calculate local uplift rates (Motyka 1998).

Glaciers and Oceanography-Comparing Seawater Salinity and Temperature Gradients near and far from Tidewater Glaciers

Location of the salinity gradient or halocline near the ice termini of active tidewater glaciers helped students to identify the extent of the fresh glacier meltwater lens at the surface, overlying the denser saline marine waters. These data could be contrasted with the entirely glacier free and marine-dominated

Figure 11. Surveying shoreline gradient.

Figure 12. Holocene glacial Lake sediments in Adams Inlet.

Figure 13. Kayaking to Adams Inlet.

Figure 14. Reid Glacier and inlet.

Figure 15. Uplifted 500-year-old stumps Halibut Point Bartlett Cove.

Figure 16. Casting bear tracks in plaster.

Photograph courtesy of Mike Hekkers

Figure 17. Students investigate Dude Creek channel and the active stream incision that carved into the rapidly uplifting intertidal silts underlying the salt marsh and meadows along Icy Strait.

Photograph courtesy of Riley Woodford

Figure 18. Fingers Bay low gradient shoreline.

Photograph courtesy of Riley Woodford

Figure 19. Steeper gradient shoreline Tidal Inlet.

Photograph courtesy of Mike Hekkers

Figure 20. Tree Corers age uplift rates.

Photograph courtesy of Melissa Skan

Figure 21. Students observe marine-terrestrial ecologic boundary on a glacial erratic Reid Inlet.

Photograph courtesy of Riley Woodford

Figure 22. Marble Island sea lions.

Figure 23. Humpback whales in bubble net feeding group.

Photograph courtesy of Mike Hekkers

Photograph courtesy of Mike Hekkers

Figure 24. Casting bear tracks in plaster.

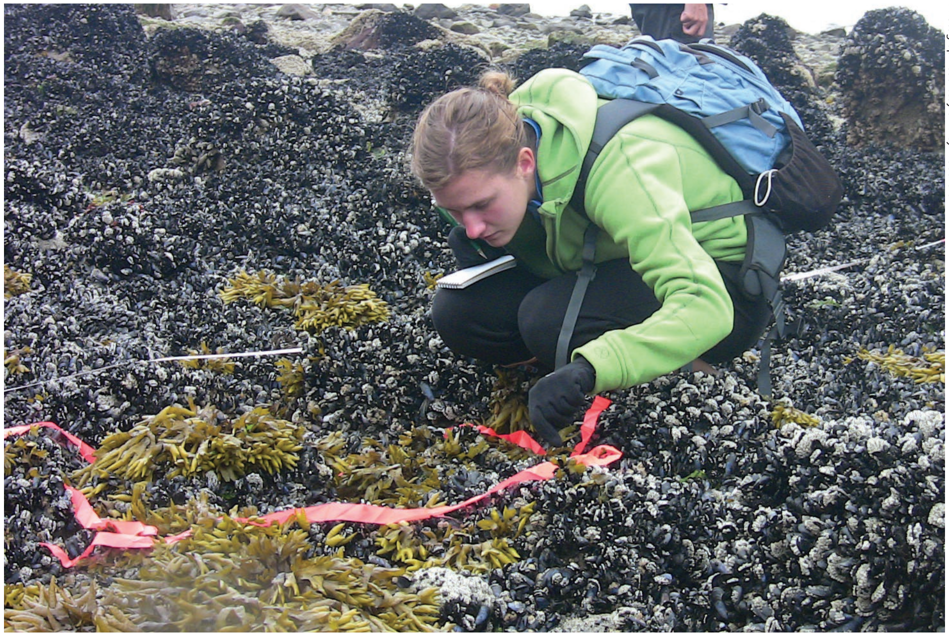

Photograph courtesy of Riley Woodford

Figure 25. Intertidal invertebrate inventory.

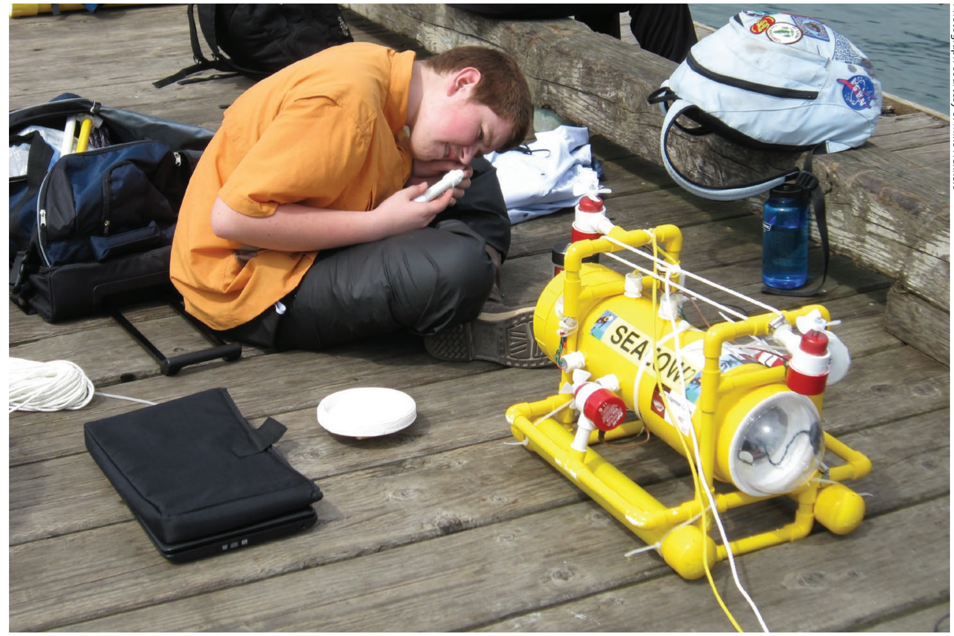
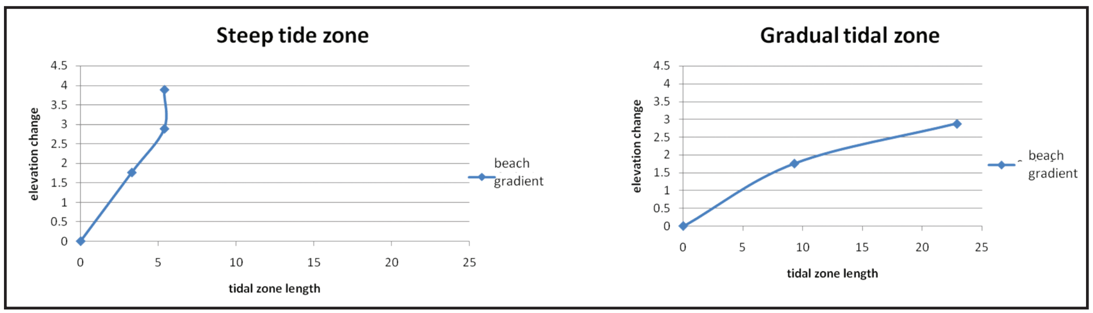

Photograph courtesy of Mike Hekkers

Figure 26. David Baker troubleshoots the operating system of his homemade ROV SEA-COW with GoProTM Camera.

Figure 27. Tidal Inlet Beach gradient survey results 2009 by Alexander Deedy (units are in meters).



system in Blue Mouse Cove midway up the bay.

The tidewater Margerie and Johns Hopkins Glaciers showed a near-surface (-10′ (3m)) temperature inversion created by iceberg calving and submarine glacial meltwater rising to the surface. This contrasts with much warmer temperatures in nonglacial Blue Mouse Cove. The halocline or abrupt change in salinity was measured at Margerie and Johns Hopkins Glaciers by students to occur at 16′ to 23′ (5 to 7 m) below the surface over different summers. This contrasts with much warmer temperatures and deeper halocline (38′ (-11.5 m)) in Blue Mouse Cove.

During two of the summers students brought their own self-built, remotely operated vehicles (ROVS, Figure 26) which they deployed with underwater cameras to view the bay's submarine environment. The ships hydrophone allowed us to listen for marine mammal communications and cruiseship noise in the underwater portions of Glacier Bay and Icy Strait.

Wildlife Ecology

Terrestrial surveys of older (two centuries) and newly deglaciated landscapes in the park enabled students to observe variation in marine invertebrate populations in the intertidal zones (Figures 25 and 27), ongoing plant succession, and large mammal population and bird densities in different regions in the park. Plaster casts were made of mammal tracks of interest (Figure 16) and birds identified during our traverses of the areas' shorelines. Sea lions hauled out on Marble Island were sometimes identified by the numbers with which they had been branded and later reported to Alaska Department of Fish and Game researchers. Seabird colonies at Marble Island and adjacent to Margerie Glacier were excellent ornithology training sites for our students.

The Value of Field Science Experiences for High School Students

Students participated in all of the disciplinary activities during the field camp. About halfway through they selected areas of interest and were tasked with taking the lead on the collection and management of their data sets, pertinent to selected disciplines. Upon our return to campus, students analyzed their data and prepared presentation slides to share at a public forum attended by campus faculty, the local community and their family members.

Preparing for oral presentations required that they take seriously our faculty admonitions to organize and catalogue their massive quantities of digital photos and movie clips, as well as to think critically about the meaning of the spatial and temporal connections linking their specific data sets with their student colleagues and the change they had observed representing over two centuries in the upper and lower parts of the Glacier Bay. The students ended their experience much changed and more thoughtful about the place they call home, with a more visceral and personal understanding about the impacts of glacial ice to this very special national park.

Acknowledgements

Special thanks to former Juneau Economic Development Council Director, Dr. Lance Miller, and to Mary Hakala, former leader of the JEDC'S Springboard Science Education program. Both have shown unusual expertise at finding funds for and making possible authentic science experiences for Alaska's youth. Thanks also to Steve Schaller and all the naturalists who helped us to make this a singular experience for Alaskan students.

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NOAT
GAAR
CAKR
KOVA
Kotzebue
Bettles
BELA
0 50 100 200 Kilometers
Alaska

Permafrost Landforms as Indicators of Climate Change in the Arctic Network of National Parks

By David K. Swanson

Introduction

Most of the land area in the five National Park Service units in the Arctic Inventory and Monitoring Network (ARCN; Figure 2) is underlain by permafrost. Permafrost is ground so cold that it stays frozen for multiple years. Certain landforms develop when permafrost thaws, and they provide a way to recognize and monitor permafrost thaw by remote sensing. At ARCN we are monitoring four types of permafrost landforms as a window into the effect of climate change on our permafrost. These landforms are active-layer detachments, retrogressive thaw slumps, degraded ice-wedge polygons, and thermokarst lakes.

Active-layer Detachments

Active-layer detachments (ALD) are small landslides that occur on vegetated slopes (Figure 1). A surface layer roughly 3′ (1 m)thick slides as a unit and accumulates as a winkled mass below. ALD are typically 30′-90′ (10 to 30 m) wide and from tens to several hundred yards/meters long. The slide leaves an elongated region of bare soil exposed on a slope, which can lead to erosion of sediment into streams (Lamoureux and Lafrenière 2009). ALD usually occur after unusually warm summer weather (Carter and Galloway 1981; Lewkowicz and Harris 2005). Thaw of the ice-rich layer that is often present in the upper permafrost produces a mud slurry that lubricates the slide (Lewkowicz 2007).

My survey of ARCN using satellite images taken between 2006 and 2008 identified over 2200 active-layer detachments, mostly in the Noatak National Preserve and Gates of the Arctic National Park and Preserve (Swanson 2012 and unpublished data), many of these ALD have re-vegetated and few new ones have formed. Climate data suggest that the unusually warm summer of 2004 triggered a large number of ALD (Swanson 2012). Many of our most slide-prone locations may have released in this event and be more stable now. But we will continue to watch for summer warm spells that could trigger ALD formation in new places, as thaw reaches depths where layers of ground ice persist.

Figure 1. A large retrogressive thaw slump on the Noatak River in the Noatak National Preserve. The distance from the uppermost point on the slump to the water is about 885′ (270 m), and the escarpment is about 49′ (15 m) high.

Figure 2. (map) The NPS Arctic Inventory and Monitoring Network (ARCN). ARCN consists of 5 NPS units: Bering Land Bridge National Preserve (BELA), Cape Krusenstern National Monument (CAKR), Gates of the Arctic National Park and Preserve (GAAR), Kobuk Valley National Park (KOVA), and the Noatak National Preserve (NOAT).

Retrogressive Thaw Slumps

Retrogressive thaw slumps (RTS) occur where a steep cut-bank in ice-rich permafrost advances into undisturbed ground as material thaws (Burn and Lewkowicz 1990; Figure 3). While ALD impact only the top 1 m or so of soil, the eroding cut-bank of a RTS is typically 2 to 10 m high. RTS often begin as an escarpment on a lakeshore or riverbank. As they advance by thawing and slumping, they can shed large amounts of sediment into the adjacent water body (Kokelj et al. 2005; Bowden et al. 2008).

My recent survey of RTS in the Noatak National Preserve and Gates of the Arctic National Park and Preserve using high-resolution satellite images from 2006-2008 detected about 700 slumps (Swanson 2012 and unpublished data).

RTS in these two parks are found mainly on glacial deposits, and they develop by thaw of glacial ice that has persisted underground for tens of thousands of years. The largest of these slumps cover over 12 acres (5 ha) and have escarpments up to 20 m high. We have monitored the growth of 22 RTS in NOAT and GAAR for years beginning in 2010, by creating 3-dimensional models from aerial photographs shot at close range from the window of a helicopter or airplane (Swanson 2013). The 3-D models are used to create detailed maps of the slumps and to measure slump growth (Figure 4)

Is the current level of RTS activity in ARCN an unprecedented result of recent climate warming, or simply the continuation of a process that has gone on for centuries? In a 73 mi^2 (190 km^2) study area in the eastern part of NOAT, I compared the number and area of RTS visible on 2008 high-resolution satellite images with aerial photographs of the same area taken in 1977 (Swanson 2012). I identified 23 RTS covering a total of 33 acres (13.5 ha) on the 1977 photos, and 35 RTS covering 52 acres (21.2 ha) on the 2008 satellite image. The slumps visible on the 1977 photos (Figure 5) were already up to 1,300′

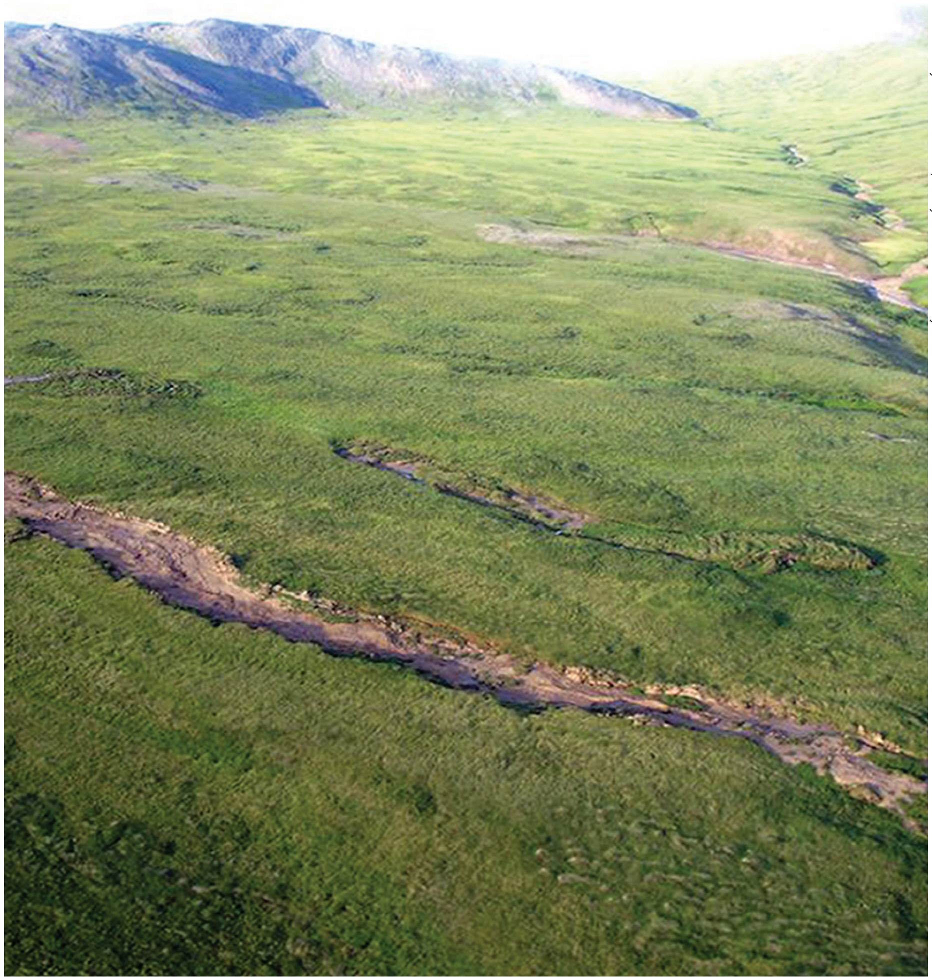

Photo courtesy of Michael Gooseff, Pennsylvania State University

Figure 3. Active-layer detachments in the Noatak National Preserve, Alaska. The nearer slide is about 328′ (300m) long and 27 yds (25m) wide. Note the mat of material that has accumulated as a lobe below the smaller, more distant slide.

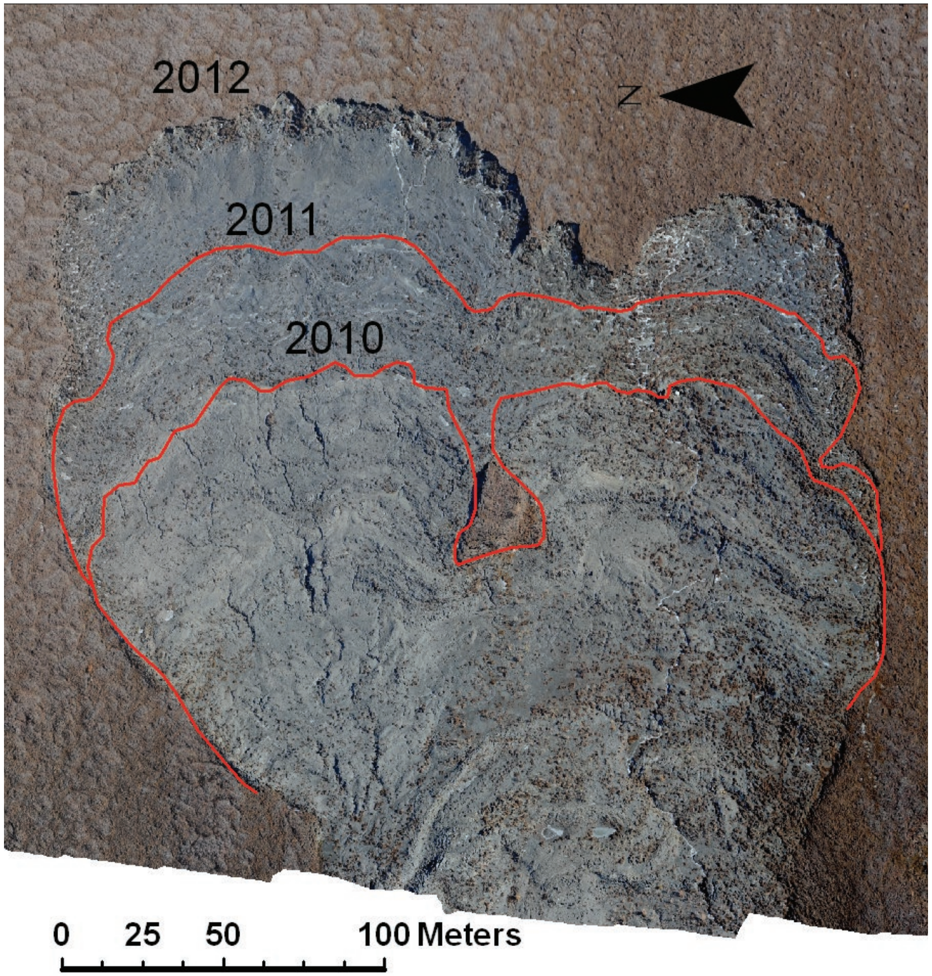

Figure 4. Growth of a retrogressive thaw slump in the Noatak National Preserve. The extent in the summers of 2010 and 2011 is shown in red on this 2012 orthophotograph. The main scarp of the slump retreated as much as 295′ (90 m).

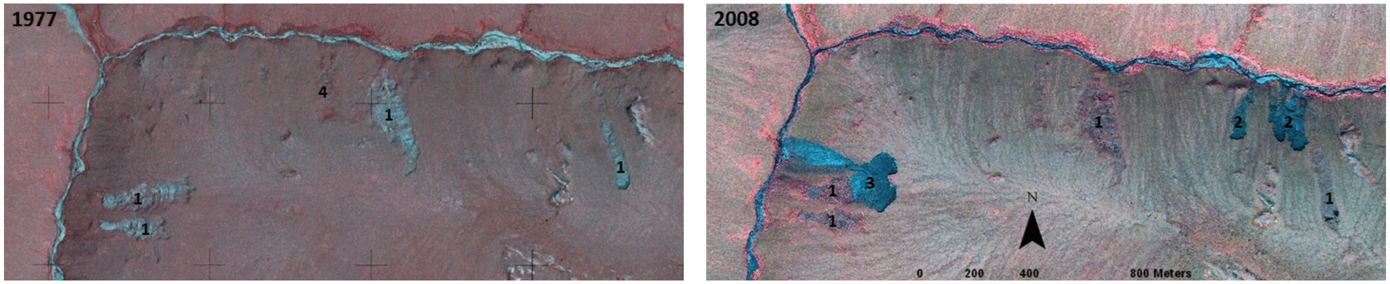

Figure 5. Retrogressive thaw slumps in the Noatak National Preserve in 1977 and 2008. The slumps present in 1977 (labeled 1 on both images) stabilized and re-vegetated with little additional growth after 1977. The currently active slumps at (2) developed in places without any activity in 1977. Active slump (3) reactivated and expanded a slump present in 1977. A re-vegetated slump is visible on the 1977 imagery (4).

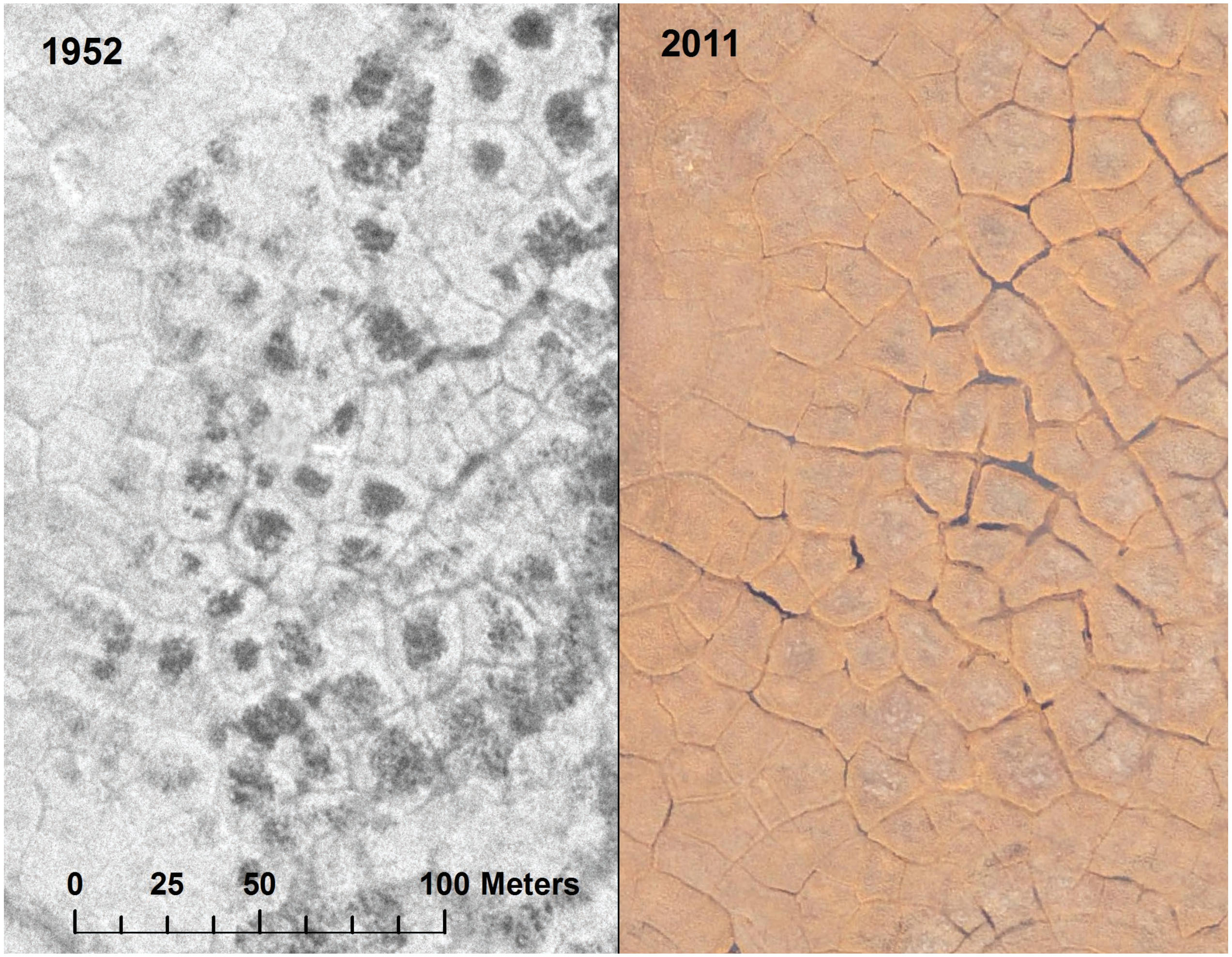

Figure 6. Ice-wedge degradation in Kobuk Valley National Park. In 1952 these were low-center ice-wedge polygons, as shown by the dark (wet) centers on the 1952 black-and white aerial photograph. By 2011 the ice wedges had partially melted to form water-filled trenches between high-centered polygons.

(400 m) long, which according to our measured rates of growth shows that they must have started growing before the beginning of the current warm climatic phase that began in the mid 1970s (Hartman and Wendler, 2005). Thus RTS were active before the post-1970s warming began, but they may be more prevalent now than before. We expect any future climate change that causes summer thaw depths to penetrate deeper will trigger new RTS and faster growth of existing RTS.

Ice-wedge Polygons

Ice wedge polygons form by contraction cracking of frozen ground in the winter. The cracks fill with meltwater the following spring; the meltwater freezes and is preserved in permafrost. After many cycles of cracking, filling, and freezing, the ice wedges can grow to a meter or more wide at the top, and create a distinctive polygonal pattern visible from the air (Figure 6). As the wedges grow, the ground adjacent to the wedge buckles upward, creating what is known as a "low-centered polygon", because the center is lower and typically wetter than the margin near the wedge.

Ice wedges are quite vulnerable to thaw because pure ice is present with little overlying insulation. When ice wedges degrade, the polygon margins subside and the polygons become "high-centered ice-wedge polygons" (Figure 7).

With a warming climate, we expect to see widespread ice wedge degradation. There is good evidence that this process began in the late 1900s around Alaska (Jorgenson et al, 2006). At the present time most ice-wedge polygons in ARCN are of the low-centered type, but we see some areas where ice-wedge degradation has produced high-centered polygons (Figures 6 and 7). We are collecting high-resolution imagery of polygon-rich terrain in the lowlands of ARCN to monitor future changes in ice wedges.

Thermokarst Lakes

Thaw of ground ice can cause subsidence, a process known as thermokarst. The depressions resulting from thermokarst are often occupied by lakes and ponds. Thaw of permafrost can cause thermokarst basins to enlarge, but it can also cause lake drainage by breaching the bank. In addition, like any other water body, thermokarst lakes can gain or lose water by climate-driven changes in the balance between precipitation and evaporation. At ARCN we are monitoring changes in the surface area of water bodies using Landsat satellite images. Several areas of thermokarst lakes in ARCN have shown marked declines in water area since the year 2000 (Figure 8; Jones et al. 2011; Swanson 2013). Much of the decline in thermokarst lake area is due to abrupt lake drainage events. Images from future years will show if this trend is continuing.

Figure 7. Water-filled trenches in Kobuk Valley National Parks formed by thaw of ice wedges.

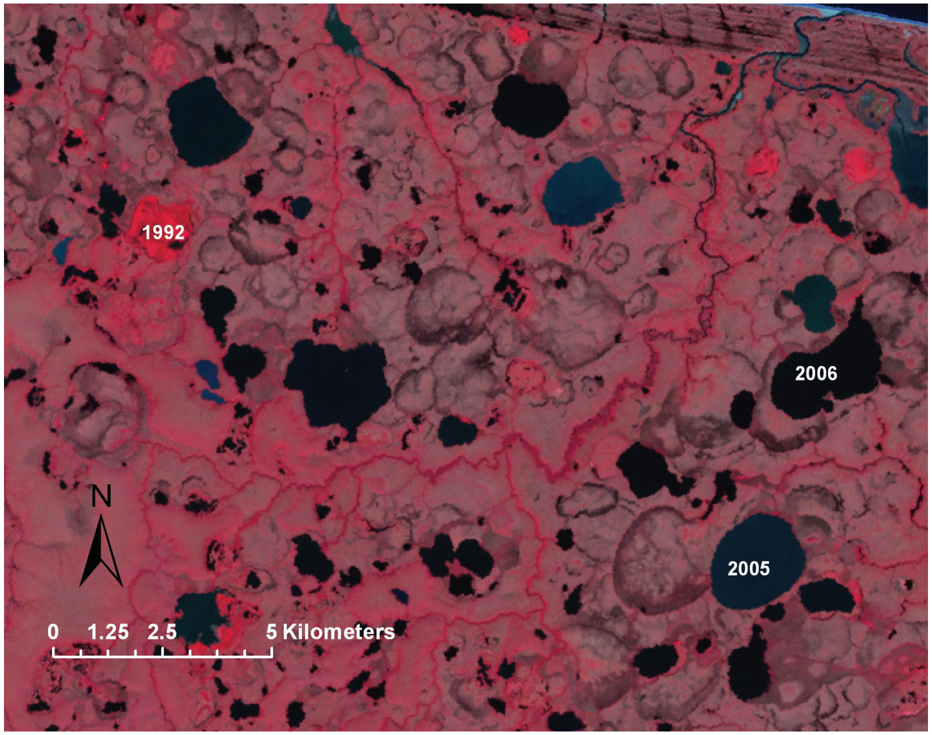

Figure 8. Thermokarst lakes in Bering Land Bridge National Preserve, Alaska, (Landsat satellite image, color-infrared color scheme, 2002). Outlines of former lake basins that have drained are visible between existing lakes. Lakes that have recently drained are labeled with the year that they last were full of water. The basin labeled "1992" is brightly colored due to lush vegetation that grew in after the lake drained, while lakes "2005" and "2006" drained not long after the image was taken.

Conclusions

There is widespread but as yet subtle evidence for landscape changes due to permafrost degradation in Alaska's national parks. If permafrost thaw accelerates in the arctic, we expect a variety of significant changes to occur, including delivery of more sediment and solutes to water bodies from ALD and RTS, continued declining area of lakes, and overall drying of the lowland landscape as ice wedges degrade and summer thaw depths increase. At ARCN we will continue our monitoring of landforms produced by thaw of permafrost to keep abreast of these potential changes.

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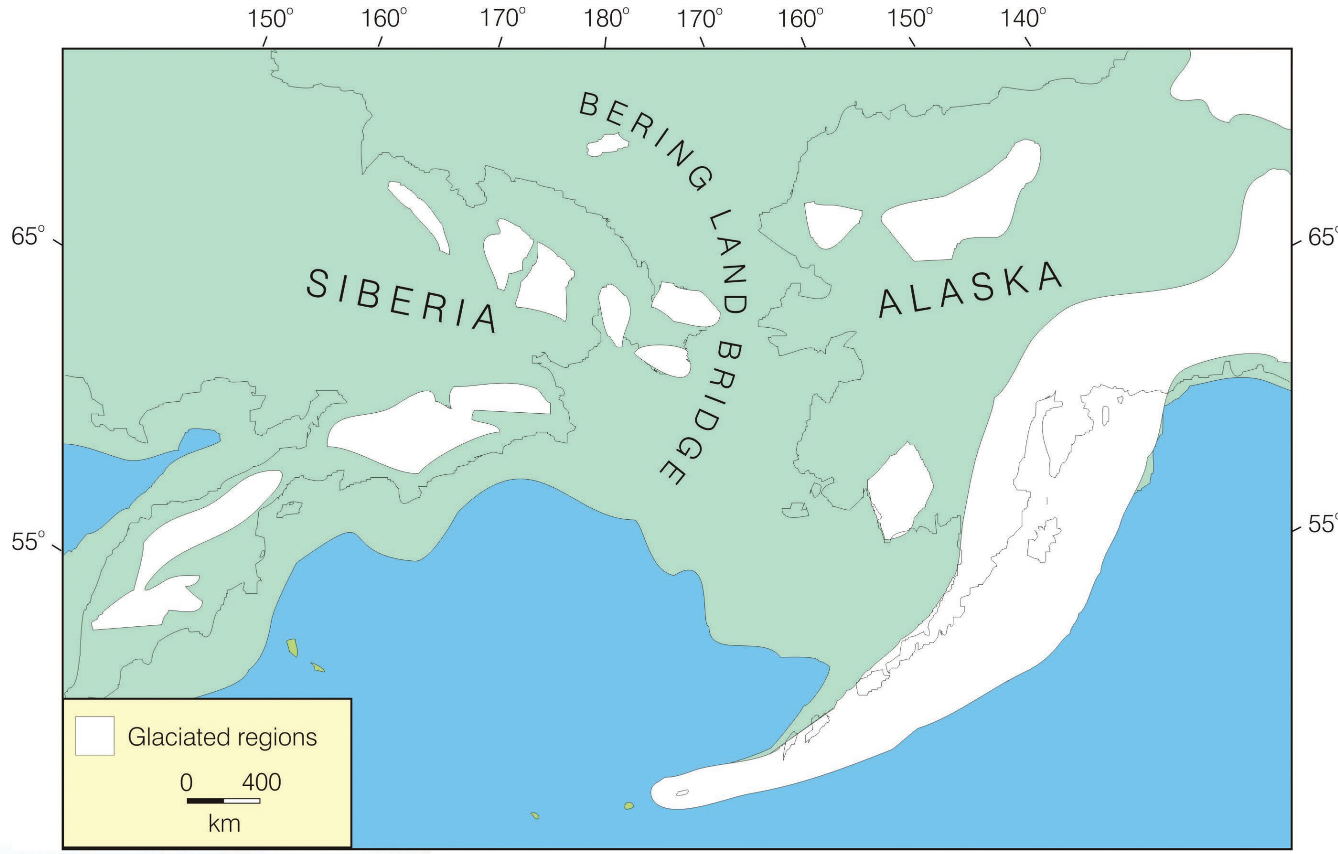
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Beringia: Lost World of the Ice Age

By Scott A. Elias

Introduction

If you live in Alaska, you may or may not be aware that you are living in the remnants of a once mighty super-continental region called Beringia. The name 'Beringia' comes from the Bering Strait region, and it is used to describe an enormous territory that extended from the Lena River, Siberia in the west to the Mackenzie River, Yukon, in the east. The western and eastern sectors of Beringia were joined together by the Bering Land Bridge (Figure 1). This land bridge formed during the glacial periods of the last 2.5 million years. Every time an ice age began, a large proportion of the world's water got locked up in massive continental ice sheets. This draw-down of the world's liquid water supply caused major drops in sea level: up to 328' (100 m) or more. Because the basins beneath the Chukchi and Bering seas are relatively shallow, they became dry land during glacial intervals. For perhaps 80% of the last million years, Alaska has been joined to Siberia by this land bridge.

The land bridge did more than link the two continents. It also ushered in a new climatic regime to the entire Beringian region by blocking Pacific moisture from entering the interior regions of both Alaska and north-eastern Siberia. Thus these regions became much drier than they are today. In fact they became so dry that their lowlands remained ice-free, even during the coldest climatic episodes of the ice ages. While virtually all of the rest of Canada, parts of western Siberia, and much of northern Europe were buried ice during glaciations, Beringia remained ice-free, except for the mountain regions that managed to catch enough moisture to build up a heavy snowpack. This made Beringia unique: a high northern region without ice cover. It could therefore serve as a refuge for arctic plants and animals, and in fact many arctic species did survive the ice ages in this refuge.

Figure 1. (map) Asia and North America were bridged by land during the last Ice Age.

Figure 2. Sampling frozen fossil sediment layers with a chain saw.

Beringian Fossils

Beringia was home to an amazing menagerie of large woolly beasts, such as the woolly mammoth, woolly rhinoceros (on the Siberian side of the land bridge), giant short-faced bear, scimitar cat, and Pleistocene camels, horses, bison and musk-oxen. The skeletons (and sometimes mummified remains) of these Beringian beasts fill museum displays from Anchorage to Whitehorse. But they were not the only animals who lived in Beringia. My interest is in the small critters: the insects that were buzzing around the landscape. Beetles, in particular, are hard-bodied insects that preserve well as fossils in the kinds of organic-rich sediments commonly found along the high river banks of Alaska's streams and rivers. Because of permafrost conditions, the fossils I examine have most often been frozen since the first winter after they died, even if that winter took place a million years ago. Frozen sediments preserve insect skeletons (theirs are on the outside, while ours are on the inside) extremely well – so much so that a fossil beetle that is upwards of a million years old looks as if it died in the last century or two. Now sometimes it is extremely difficult to get this frozen sediment out of the ground. It can be as hard as concrete. I have had to resort to using chain saws to cut blocks of peaty sediments out of the ground (Figure 2). A colleague of mine even tried dynamite! But in the end, such efforts are rewarded by a treasure trove of shiny, highly decorated beetle 'bits' that I can study and identify under the microscope.

Beetles are the largest group of insects on the planet. We do not have an exact count, but recent estimates of the beetle fauna put the total number of species at about 1500 that live in Alaska (Anderson 1997). This represents three-quarters of the number of all the Alaskan plant species (Hultén 1968); it is more than triple the number of birds (Armstrong 1995), and about fourteen times the number of mammal species. So the beetles are out there – in large numbers – telling us things about the landscape by where they live, what they eat, how cold they can take it in the winter, and how warm they need it to be in the summer. In fact their relatively high diversity in Alaska is, itself, a product of their longevity in the Beringian refuge.

The Nature of Beringia

Eastern Beringia, the unglaciated lowlands of Alaska and the Yukon, was not a barren arctic wasteland during the last glaciation – far from it! Instead, it was a very productive landscape, dominated by grasses and other herbs, mixed with arctic tundra plants. This ecosystem has been called 'steppe-tundra,' and it was extremely widespread, from the Yukon region in the east, all the way across the unglaciated parts of Siberia, to the unglaciated parts of Western Europe. The steppe-tundra supported a wide range of large grazing mammals and their predators (Figure 3). Herds of Pleistocene camels, bison, horses, mammoths, and musk-oxen grazed the dry grasslands of interior Alaska and the Yukon. All but the musk-ox died out at the end of the last glaciation, between about 15,000

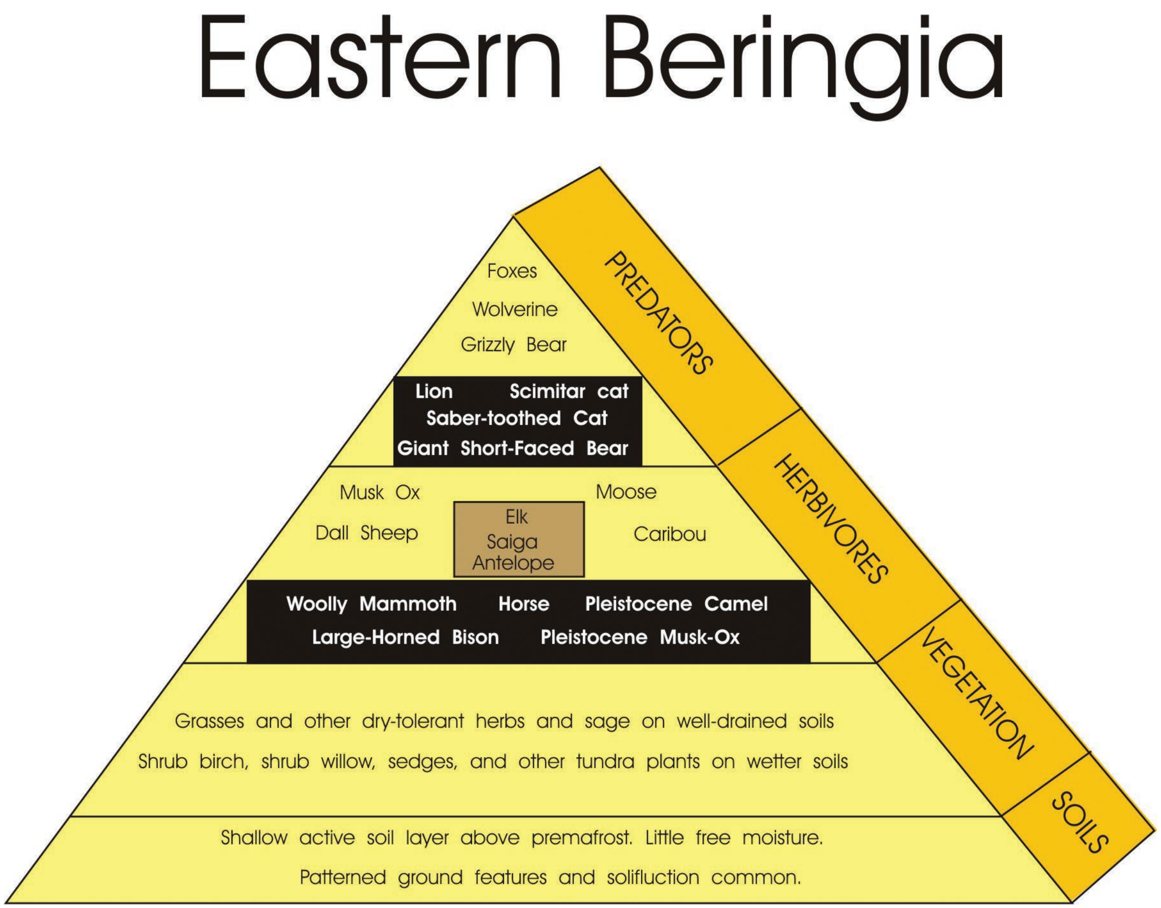


Figure 3. Many large mammal species populated Beringia during the ice age.

and 11,000 years ago. But running around beneath the feet of these ice-age behemoths were hundreds of species of beetles. None of the steppe-tundra beetle species became extinct. They survive today, although some of them now live in different regions than they did in the ancient past. By studying their modern ecology, we can piece together what the ancient Beringian landscapes were like.

One of the puzzles that intrigues Beringian scientists is the actual extent of the steppe-tundra ecosystem. How much of Alaska did it cover? Did it spread out onto the Bering Land Bridge, or was that region covered by some other kind of vegetation? Did it form a continuous band of grassy landscapes that linked Western Beringia (unglaciated northeastern Siberia) to Eastern Beringia, or was there an ecological gap between the two mega-regions? I have been fortunate enough to be able to address some of these questions in my fossil beetle research. It turns out that there are beetle species that are quite characteristic of the steppe-tundra habitat. Some of these are plant feeders associated with the semi-arid steppe-tundra vegetation, such as beetles that feed on sage brush. Some are predators that live today on the cold grasslands of north western Canada. On the flip side of the equation, there are also groups of beetles that are completely unsuited to steppe-tundra, but flourish in the low shrub tundra habitats we see today in north western Alaska. Thus, by identifying which groups of beetles are found in a fossil assemblage, it is relatively easy to identify which ecosystem existed at the time and place the beetles were living. There is a beetle 'signature' on the landscape that can differentiate between the different ancient ecosystems (Figure 4).

Fossil Sampling

As we all know, Alaska is an enormous state, and much of it cannot easily be reached except by float plane or helicopter (very expensive means of transportation). So unlike some other parts of the world, where fossil study sites dot the landscape like a veritable pin cushion, the number of fossil study sites in place like western and northern Alaska are few and far between. Nevertheless, some patterns are emerging that are shedding light on the steppe-tundra question. One of the most fascinating sources of fossil materials has been cores of sediment that were drilled from the sea bed in the Bering and Chukchi Seas. Back in the 1970s and 1980s, the U. S. Geological Survey commissioned a study of the geology of the Chukchi and Bering Sea beds, mostly as an aid to the development of oil and gas supplies. The USGS punched holes into the sea floor in many localities, taking cores that went down into the Cretaceous in some cases (where the oil and gas deposits are to be found). But at the very tops of those cores, a meter or more of soft sediments were sampled. Those sediments accumulated on the surface of the Bering Land Bridge, during the last ice age. Colleagues and I were able to sample organic-rich sediments that contained plant detritus, pollen, and insects that had lived and died on the land bridge. Out of the thousands of cores taken by the USGS, we were able to find Late Pleistocene fossils in about 20 (Figure 5). The peaty sediments we studied most likely accumulated in shallow ponds or bogs on the land bridge.

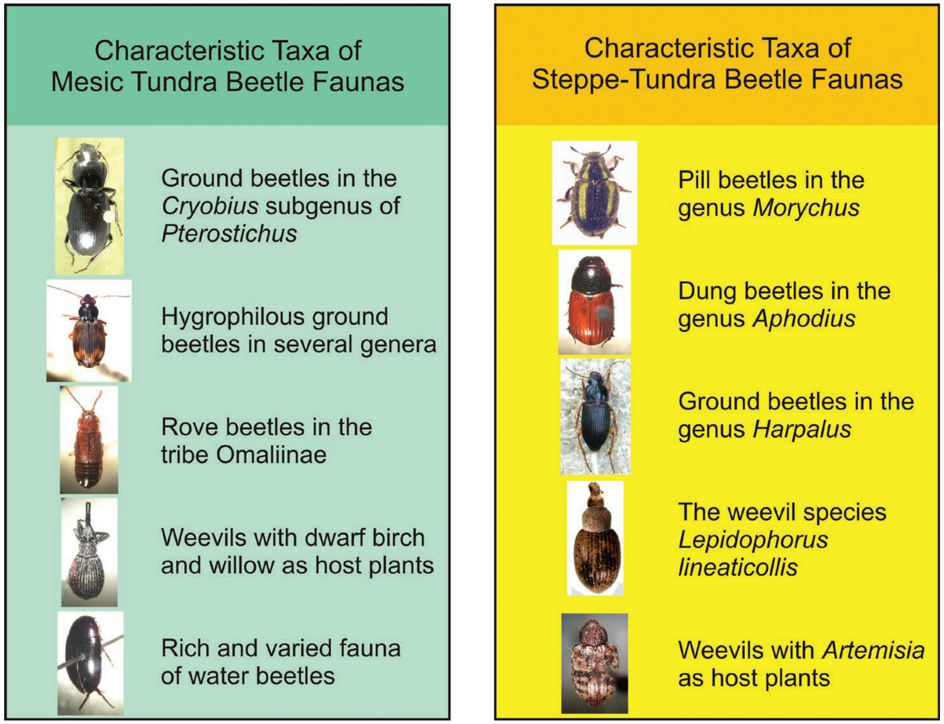
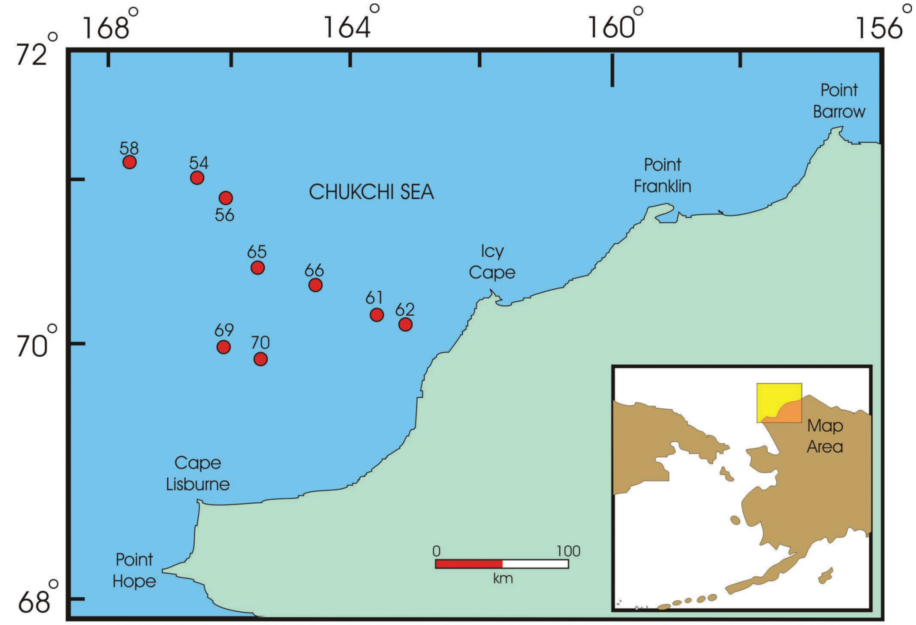


Figure 4. Different habitats can be characterized by the presence or absence of certain beetle species.



What was the Land Bridge Like?

Our results, combined with those of other scientists, are starting to reveal an interesting pattern (Elias et al. 1996). Most of the ancient ecosystems we studied from the land bridge were quite similar to what is found in north western Alaska today. This is called mesic tundra: low tundra vegetation that requires a medium amount of moisture to grow (Figure 6). It is dominated by dwarf shrubs of birch and willow, mixed with tundra herbs. There is very little grass in it – not enough to feed a hungry mammoth, for instance. This zone of mesic tundra covered much of the central and northern parts of the land bridge, and it extended east onto parts of upland Alaska, but not in a uniform pattern (Figure 7). Parts of south western Alaska around the Bristol Bay region were dominated by mesic tundra, as well as much of north

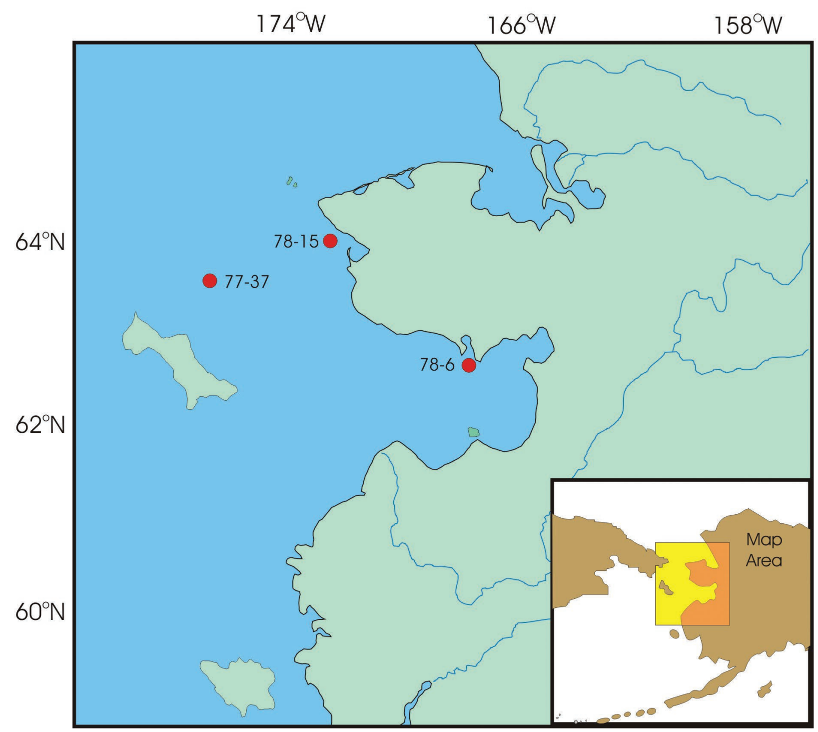


Figure 5. Locations of sea bottom core samples containing Late Pleistocene age fossils.

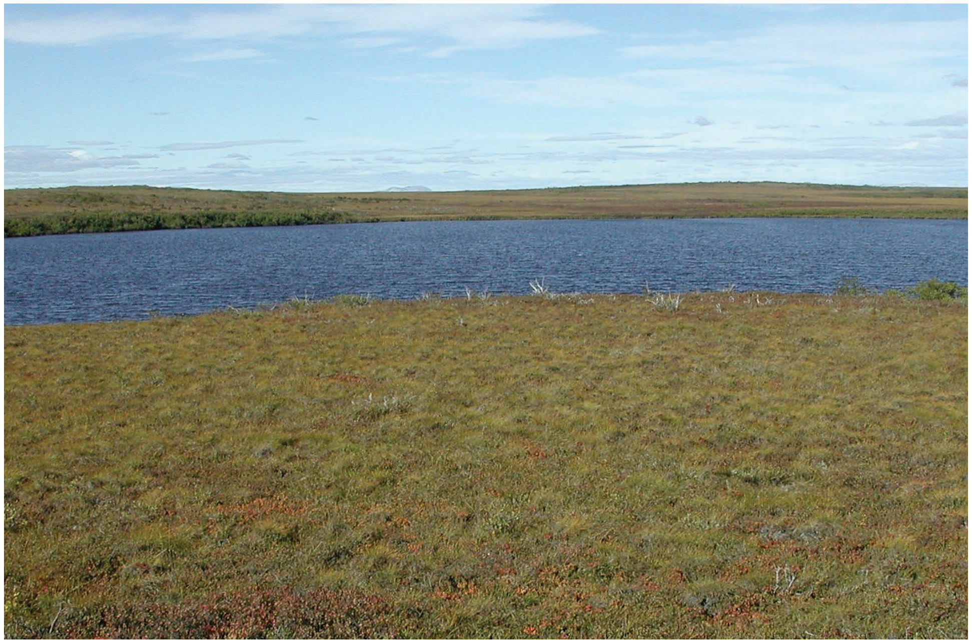


Figure 6. Mesic tundra is a low tundra vegetation, requiring a medium amount of moisture.

western Alaska. But parts of the Seward Peninsula clearly had a cover of steppe-tundra. Furthermore, some of the modern-day islands in the Bering Sea, including St Lawrence Island, had steppe-tundra vegetation. These islands would have been highlands overlooking the broad plains of the ancient land bridge. So the pattern that is emerging is that much of the center of Beringia – the land bridge – was wetter than the surrounding uplands on either side. Paleontologist Dale Guthrie (2001) has called this the buckle in the steppe-tundra belt.

This wetter region, with its dwarf-shrub cover, may have posed a barrier to migration for some (but not all) of the large grazers that lived on either side of the land bridge. For instance, the woolly rhinoceros lived throughout Western Beringia, as well as other grassy parts of Eurasia, during the Late Pleistocene. This rhino made it right up to the edge of the Bering Land Bridge, but it did not manage to cross over (Elias and Crocker 2008). Its feet were adapted to firm, dry ground, and it

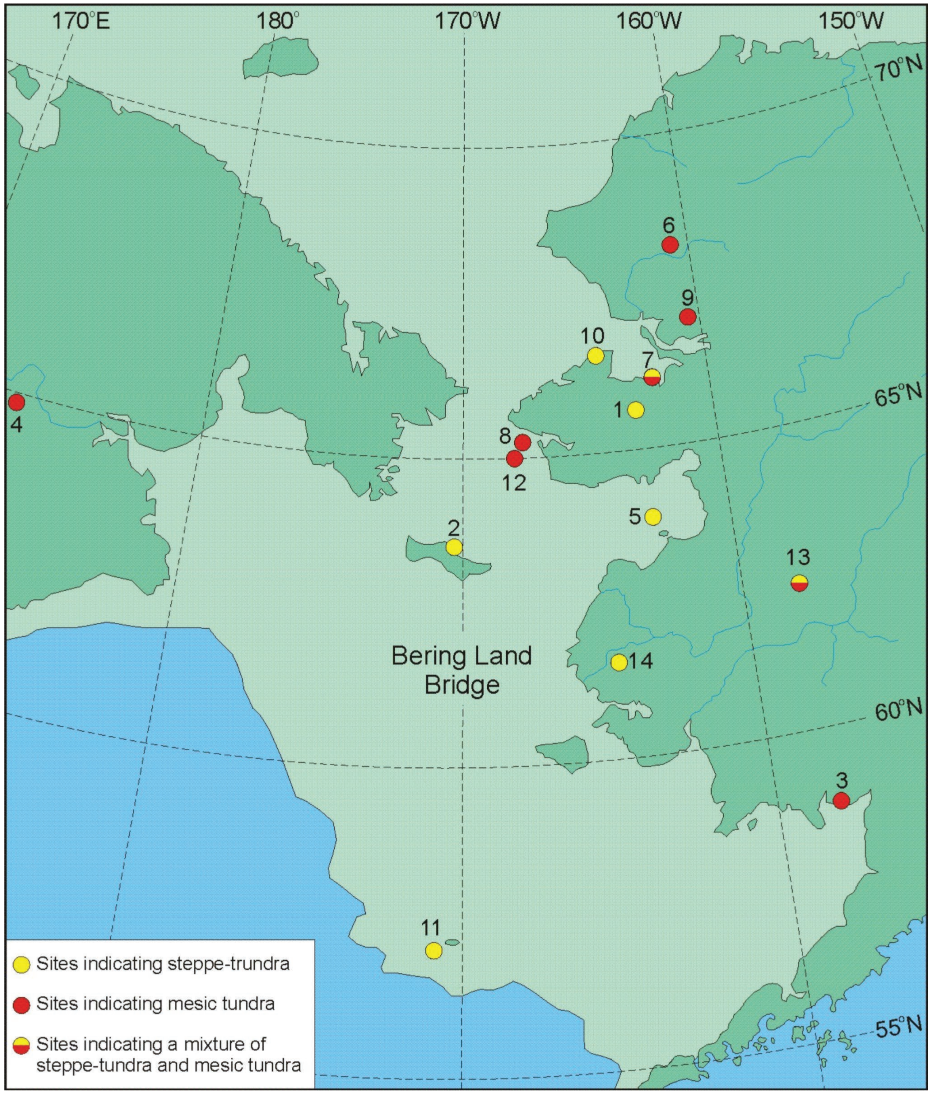


Figure 7. Mesic tundra covered much of the central and northern parts of Beringia, extending east onto parts of upland Alaska.

needed large quantities of grasses to survive, so it may have shied away from the damp, shrubby land bridge. But the land bridge did not prevent other species from migrating across. The woolly mammoth (Figure 8), for instance, managed to live on both sides of Beringia. Alaskan national parks have provided many of the fossil sites used in the study of ancient Beringian landscapes and ecosystems. Important sites have been studied in Denali National Park, Gates of the Arctic National Park and Preserve, Noatak National Preserve, Bering Land Bridge National Preserve, and Katmai National Park and Preserve. Park Service scientists have worked in collaboration with researchers from the U. S. Geological Survey and various universities in Alaska and the lower 48 states to develop Beringian studies. One aspect of the research that interests all parties is the human story. When did our species enter the New World? Did they use the Bering Land Bridge to get here, or did they embark from Asia by canoe, and paddle along the Pacific coast of the Americas? What were the conditions like when they first arrived in Alaska? As discussed in a recent book by Hoffecker and Elias (2007), the human story cannot be separated from the environment. Perhaps these little beetles have as much or more to tell us about about ourselves than do the big beasts!

Figure 8. Woolly mammoths lived on both sides of Beringia.

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Glacier-fed Rivers and Climate Change in Alaska Parks

By Alexander Milner

Introduction

Glaciers are distributed globally, covering about 10% of the Earth's surface and storing about 75% of the world's freshwater. Hence, glaciers contribute significantly to river flow and water resources across the globe (Fleming and Clarke 2005), and provide important ecosystem services for society in terms of hydro-power, agriculture, and water supply (Barnett et al. 2005). This is particularly the case in Alaska where approximately 35% of the runoff is from glaciers (Mayo 1986) and glacial runoff can have a marked effect on yearly, seasonal, and daily river discharge fluctuations where glacierization (glacier landcover) in a basin exceeds 5%. Much of this runoff originates from glaciers within Alaska national parks. Climatic conditions determine the total annual runoff from and the net storage of perennial snow and ice within the basin; hence inter-annual stream flow variations reflect glacier mass-balance fluctuations. Seasonally glacial rivers in the northern hemisphere typically have very low or no discharge in winter; flows begin increasing in early May as solar radiation increases to reach a summer peak at maximum glacier melt. Discharge then declines gradually until freeze-up in November and December. Glacierized environments are demonstrably one of the most vulnerable to climate change because of interconnections between atmospheric forcing, snowpacks/ glacier mass-balance, stream flow, water quality, and hydrogeomorphology (physico-chemical habitat), and river ecology (McGregor et al. 1995).

Not only are most glaciers shrinking (i.e. both thinning and retreating, see Figure 2), but that the rate at which they are changing has accelerated over the last 2-3 decades (Haeberli et al. 2007). Over the last century, mid-latitude and arctic glaciers have generally been shrinking (including most in Alaska), while some in marginal environments have disappeared (Meier et al. 2003). Measurements of glacier mass-balance outside polar regions are mainly negative, with a few exceptions e.g. Scandanavia.

Glaciers play a major role influencing river flow regimes with peak glacier-melt occurring during mid-late summer following retreat of the transient snowline (Hannah et al. 2005). The hydrological behavior of basins with as low as 10 % ice cover are strongly influenced by the balance between accumulation (gain) and ablation (loss) of glacier mass (Fountain and Tangborn 1985). Glaciers can maintain stream flow during the summer dry season when rivers in non-glacierized basins display low flow (Hannah et al. 2005). Rivers with meltwater inputs provide habitat for fisheries (Richardson and Milner 2004) and a number of rare and endemic macroinvertebrate species (Brown et al. 2007).

Hydrological response to retreating glaciers

For larger receding glaciers, an initial increase in glacial meltwater generation may occur due to increased energy inputs, earlier disappearance of reflective snow cover and exposure of lower albedo ice (Milner et al. 2009). However, this initial flow increase will be followed by reduced glacial runoff in the long-term due to an ensuing negative glacier mass-balance (Stahl et al. 2008). However for many smaller mountain glaciers reduced glacial meltwater runoff is occurring presently as glaciers recede.

Glacier-fed rivers and their biotic communities

Many of the large glacier-fed rivers in Alaska (e.g. the Susitna River flowing from the south side of the Alaska Range in Denali National Park) possess a complexity of habitats adjacent to the main glacier-fed channel, including side-channels and side-sloughs. Juvenile king salmon use the side channels for rearing, whilst the turbidity and invertebrate drift into these channels can provide both cover and food resources. These side-channels and sloughs are sustained by melt waters of the main channel (Richardson and Milner 2004) and juvenile chinook salmon overwinter in these habitats. For many of these systems in northerly regions, winter is a critical period when overwintering mortality for salmonids can be high if they are unable to migrate to suitable refugia (i.e. channels off the mainstem). A significant positive correlation exists between the survival of young salmonids during the winter and the amount of winter discharge or winter groundwater inputs (Fleming 2005). Therefore, any changes in water source contributions that enhance winter flows would be beneficial to salmonid populations.

The effect of shrinking glaciers on fish populations will depend upon whether the reduction in mass-balance causes an initial increase in the glacial runoff contribution to the river system (as outlined earlier) or a decrease. Increased glacial runoff will cause an increase in summer flow peaks and potentially the duration of higher flows, which will enhance the

Figure 1. Exit Glacier from the Harding Ice Field feeding the Resurrection River.

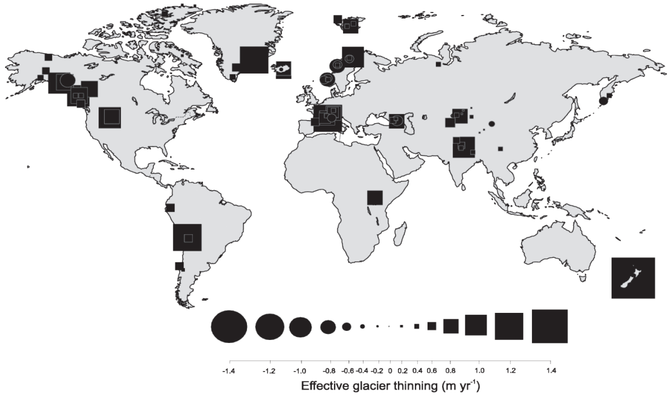

Figure 2. Effective thinning rates of mountain glaciers from 1970 to 2004 using data from Dyurgerov and Meier (2005).

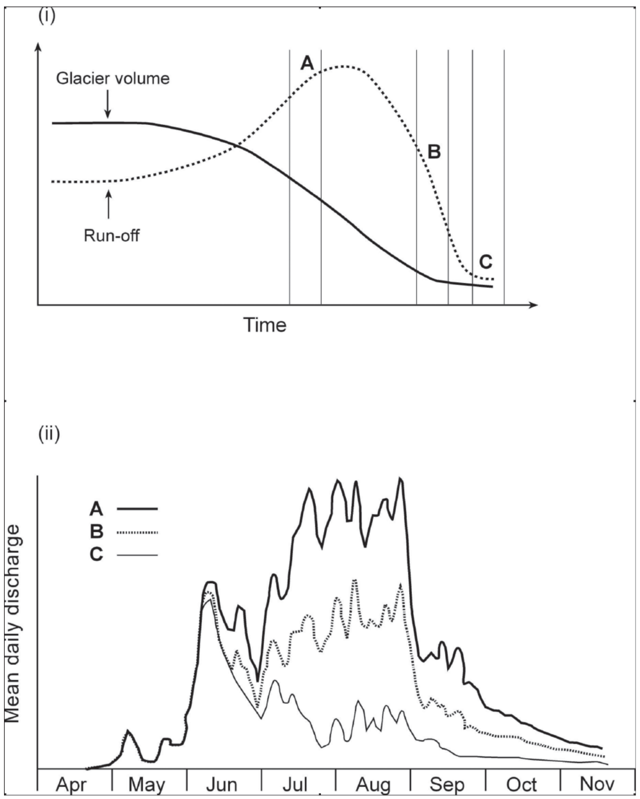

Figure 3. (i) Hypothetical relationship of river runoff to decreasing glacier volume from initially being stationary, and (ii) anticipated hydrograph response to three different stages of glacier volume reduction (A,B,C) (after Milner et al. 2008).

migration of adult salmon to their spawning grounds, either in the river mainstem or in associated tributaries and off-channel habitats. Increased glacial runoff will also increase mainstem spawning habitat and cover in the side channels. This migratory and spawning habitat aspect of increased glacial runoff applies principally to larger systems fed by glaciers in Alaska and Canada.

Glacier-fed rivers support a unique flora and fauna driven by the overriding influence of water temperature and channel stability (Milner et al. 2001). However there is a strong temporal element to these conditions and in the spring and autumn when the glacial component is reduced, improved water clarity and channel stability in the channel allow for periods of extensive algal growth and benthic invertebrate production. These can be looked on as "windows of opportunity" for these organisms before and after the harsher conditions of summer when glacier melt is at its maximum.

Glacier-fed rivers close to the source are unique in that they support a deterministic assembly of macroinvertebrate communities that are similar worldwide due to the overriding variables of low channel stability and water temperature (Milner et al. 2001). A number of these taxa are cold stenotherms restricted to headwater reaches. With climate change and where glacial runoff becomes reduced, channel stability and water temperature will increase and suspended sediment/turbidity decrease. The development of stream macroinvertebrate communities in Wolf Point Creek in Glacier Bay with reduced percent glacierization of a remnant ice sheet provides some general insights into what will happen when glaciers retreat with reduced glacial runoff (Milner et al. 2008). There

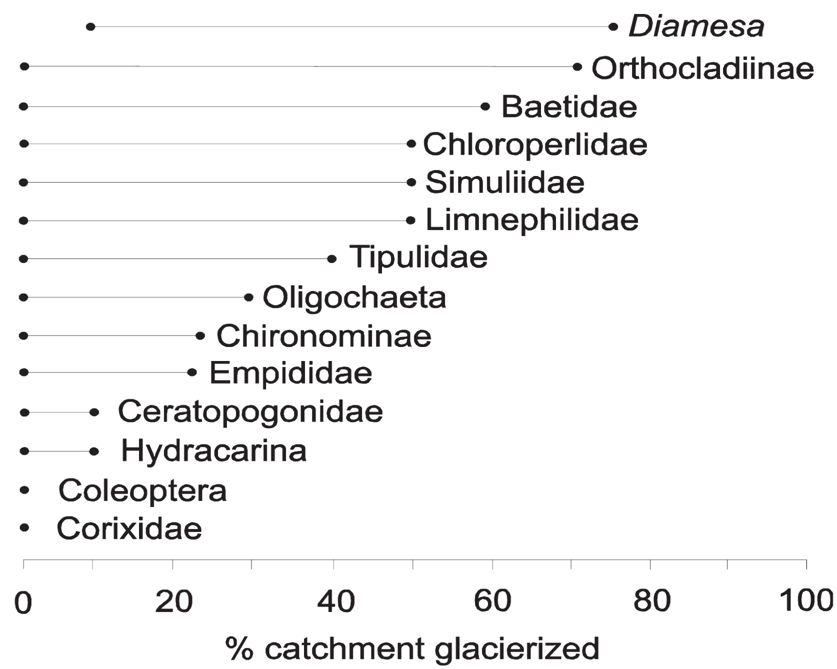

Figure 4 Response of individual macroinvertebrate taxa to change in catchment glacierization in Wolf Point Creek, Glacier Bay, Alaska (Milner et al. 2008).

was a strong negative relation between % catchment glacierization in the Wolf Point Creek watershed and the diversity of the benthic community (Figure 4) with only five taxa (all chironomids) found in the stream at 70% glacierization which increased to 24 taxa at 0% glacierization. Of the chironomids (non-biting midges), Diamesa were not found when % glacierization was <15%. Baetidae (mayflie) were found at 60% glacierization, and Chloroperlidae (stoneflies), Limnephilidae (caddisflies) and Simuliidae (blackflies) <50% glacierization. Hydracarina and Cerapotogonidae occur for <10% glacierization and Coleoptera (beetles) and Gastropoda (snails) when glacial influence had disappeared. The principal mechanism of this change appears to be maximum water temperature, which has increased in Wolf Point Creek from 68 F (20 C) at 70% glacierization in 1977 to 64 F (18 C) at 0% glacierization in 2002 ($r^2 = 0.93$ for water temperature vs. macroinvertebrate diversity). However, other mechanisms are involved in this change in community structure over time including biotic interactions and changes in geomorphological habitat (i.e. increase in glides and pools). Clearly, this evidence of a strong relationship between % catchment glacierization and macroinvertebrate taxon richness indicates that changes in glacial runoff into streams and rivers with glacier shrinkage will significantly change the structure of benthic communities.

These changes involve greater local (alpha) diversity and greater abundance which should benefit fish populations. However this is not the full story. Brown et al. (2007) suggested that some endemic species will be lost as glacial meltwaters decrease. This causes a decrease in overall regional (gamma) diversity as these cold stenothermic species become extinct from the regional pool and this was highlighted by Jacobsen et al. (2013) for other areas of the world than Glacier Bay, including the Andes and the European Alps.

Figure 5. Groundwater-fed channels on a terrace of the glacierized Tolkat River floodplain, Denali National Park.

Glacierized valleys and biological hotspots in Alaska

In many large glacierized valleys of interior Alaska with gravel bed rivers, upwelling glacial runoff further down the floodplain supplies groundwater-fed channels. Some of these channels flow permanently throughout the year creating biological hotspots very different in character than the main channel. At these hotspots plant growth, particularly willow, is evident across the terrace of another wise barren floodplain. These groundwater fed-streams were characterized on a floodplain terrace of the Tolkat River in Denali National Park by Crossman et al. (2011) who showed they provide stable environments in terms of reduced variability in flow and water temperature regimes, with a negligible bed movement. These groundwater channels support higher diversity and abundance of macroinvertebrates than streams fed by surface runoff and can be important overwintering habitat for fish, like Arctic Char. A model using available satellite imagery and calibrated in Denali National Park and validated in Wrangell St. Elias National Park developed by Crossman et al. (2012) indicates these water-fed channels are extensively distributed throughout these two national parks. However time series analysis of aerial imagery of one of the floodplain terraces within the Tolkat River valley indicates the active length of these channels and the extent of vegetation along the length of the terrace has decreased over time, presumably due to reductions in the amount of glacier runoff as the glaciers shrink in mass balance. In terms of climate change, it is likely that the extent of these biological hotspots created by glacial runoff will decrease in the future with a reduction in the availability of these important habitats.

Glacial recession and the creation of new habitat in Alaskan Parks.

An intriguing aspect of large scale glacial recession in coastal Alaska is the creation of new habitat open to colonization by biotic communities including anadromous salmon and other fish communities. Although many recently-formed streams are relatively short in length, potential recruitment of new salmon stocks is significant at a time when other stocks in the Pacific Northwest region of North America are threatened by anthropogenic activity. The recent creation of new stream habitat has been extensive along the coasts of southeast and southcentral Alaska (including both Glacier Bay and Kenai Fjords National Parks) linked both to climate change and local environmental conditions (Milner et al. 2008; 2011). In Glacier Bay, pink salmon (Onycorhnchus gorbuscha) have established substantial populations from a small colonizing population of spawners within a few generations, and other species rapidly colonize, including non-anadromous fish (e.g. sticklebacks) (Milner et al. 2008). Similarly in Kenai Fjords National Park in southcentral Alaska, 500 mi (800 km) northwest of Glacier Bay on the Kenai Peninsula, glacial recession has produced new stream habitat, notably in McCarty Fjord where McCarty Glacier has receded from a Neoglacial maxima in 1840. On the eastern side of the fjord this recession has created three streams all possessing lakes (dates of formation in brackets) as their principal source; namely Delusion (1980-1985), Desire (1935-1940), and Delight Lakes (1920-1925). Juvenile Dolly Varden were found to be the dominant salmonid in the younger system but were replaced by juvenile coho salmon in the older streams (Milner and York 2001). Due to the presence of lakes, sockeye salmon are also found and were first observed in Delusion Lake in 1987. By 1992, over 1000 sockeye salmon were spawning along the shallow margins of the upper lake. In less than 100 years sufficient numbers of sockeye salmon had colonized Desire and Delight Lakes to support a commercial fishery in McCarty Fjord that exceeded 50,000 in high years of the early and mid 1980s (Milner 1995). In recent years these numbers have declined, and the 10 year average to 2012 was 16,500 sockeye salmon. In addition almost 500,000 pink salmon were caught in the commercial fishery during the same time period associated with this district, many having their natal streams within Kenai Fjords. However in Glacier Bay, a number of sockeye salmon populations have been lost as lakes have been cut off or disconnected with stream development. Salmon carcasses left in the stream after spawning provide a significant source of marine-derived nutrients and organic matter, which can promote productivity in other parts of the ecosystem.

Summary

Glacier-fed rivers are unique biotopes with an inherent complexity that are widespread throughout Alaskan national parks. Climate change is predicted to have a higher impact at higher latitudes and altitudes, and these systems will be potentially susceptible to significant change that will affect their biotic communities including salmonid populations. Reduced glacial runoff will decrease the areal extent of upwelling channels and biological hotspots. The creation of new salmon habitat by glacial recession in coastal parks has added significantly to salmon stocks in Southeast and Southcentral Alaska.

Figure 6. Aerial photographs of the Stonefly Creek watershed (Glacier Bay, Alaska, USA) in four different years from 1975 to 2003. The scale in photographs (a)–(c) is 1:20,000; in (d) it is 1:10,000 (adapted from Milner et al. 2011).

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Observations of Changing Conditions in Northwest Alaska and Impacts on Subsistence Fishing Practices

By Katie Moerlein, Courtney Carothers, and J. Andrés López

Introduction

The global warming trend of the past century is amplified at high latitudes. Arctic temperatures in recent decades are the highest they have been over the past 400 years (Overpeck et al. 1997). Environmental changes observed over the last four decades suggest that the effects of climate change in the Arctic are already recognizable. These changes include melting sea ice, rising sea levels and coastal erosion, permafrost thaw, and the range extension of some fish species (Hinzman et al. 2005). Global climate change and the regional intensity of change in the Arctic have significant implications for the remote, indigenous communities of the North, who are closely tied to their surrounding environment. Residents of the Arctic recognize that regional climate has changed within living memory (Krupnik and Jolly 2002).

The complex relationships between changing climatic factors, ecosystem dynamics, and effects on fish populations raise concern for management bodies and resources users, who are searching for ways to prepare for and respond to potential changes in the distribution and abundance of key fish species and in ecosystem dynamics (Stram and Evans 2009). Few studies have specifically addressed the impact of climate change on subsistence fishing activities in remote Alaskan communities and the perceived importance of these impacts. Given the dependence of communities in northwest Alaska on subsistence fishery resources, it is imperative to better understand the current and potential impacts of climate and other cultural changes on these fisheries. Active and experienced fishers throughout arctic Alaska possess a deep body of knowledge about local fish resources and environmental interactions accumulated over generations, which we refer to as traditional ecological knowledge. This rich body of knowledge is often under-recognized and under-utilized in conventional studies of environmental change and its impact. Understanding and addressing a process as complex as climate change are improved with the inclusion of these local perspectives.

Figure 1.

Ethnographic investigation

Ethnographic methods provide a useful set of tools for studying and seeking to understand traditional ecological knowledge. With an emphasis on observing and participating in the daily lives of people, ethnographic research provides powerful insights into the holistic and integrated nature of subsistence practices and the factors shaping subsistence economies. With funding from U.S. Fish and Wildlife Service, Office of Subsistence Management, and the National Park Service George Wright Melendez Climate Change Fellowship, we worked in the Iñupiaq communities of Noatak, Shungnak, and Selawik in northwest Alaska to document local observations of changing environmental conditions and impacts on subsistence fishing practices. We conducted semi-structured ethnographic interviews (Spradley 1979) with local residents knowledgeable about the local environment and subsistence activities to explore knowledge about climate and ecological changes of concern for subsistence fisheries. We interviewed 17 people in Noatak, 13 people in Shungnak, and 21 people in Selawik. We guided the interview discussions by asking questions about the distribution and abundance of targeted subsistence fish, observations of species-level changes, other ecological changes, and weather and seasonal patterns that may affect fishing activities. During the semi-structured interviews we actively avoided asking leading questions about "climate change" as a broad phenomenon, but instead queried people about their observations of changes in environmental and ecological conditions over their lifetime of engaging in subsistence practices.

We also implemented a cultural consensus survey (Romney et al. 1986) in each community to assess the degree of agreement among knowledgeable fishermen about climate change observations. The consensus survey consisted of a list of 44 agree/disagree propositions that we developed from qualitative analysis of the ethnographic interviews. During the survey, we asked respondents to think about environmental conditions now compared to about 20 to 30 years ago. We focused on this time period because interview participants said that this was around the time they started noticing major changes in local conditions. In each community we worked with local leaders to compile a list of knowledgeable elders and active fishermen to survey. We surveyed 24 local experts in Selawik, 25 in Noatak, and 16 in Shungnak.

Observations of changing conditions

The people of Noatak, Selawik, and Shungnak possess extensive knowledge of current and historical weather conditions, ecological conditions related to important subsistence fish species, harvesting and processing of fish, as well as the complex links between these phenomena. Overall, we found consistent agreement about a range of perceivable environmental changes affecting subsistence fisheries in this region. Residents are noticing changing weather conditions, shifting break-up and freeze-up patterns, lower river and lake water levels, melting permafrost, increased river bank erosion, and changing populations of some local animal species. These changes have implications for subsistence fishing practices, such as more difficult boating conditions, unfavorable weather for processing fish, poor water conditions for fishing activities, increasingly unpredictable fish movement patterns, and increased blockage of waterways by beaver dams. We discuss these observations and impacts in more detail in the following sections, and include direct quotes from interviews in order to allow local experts to speak for themselves.

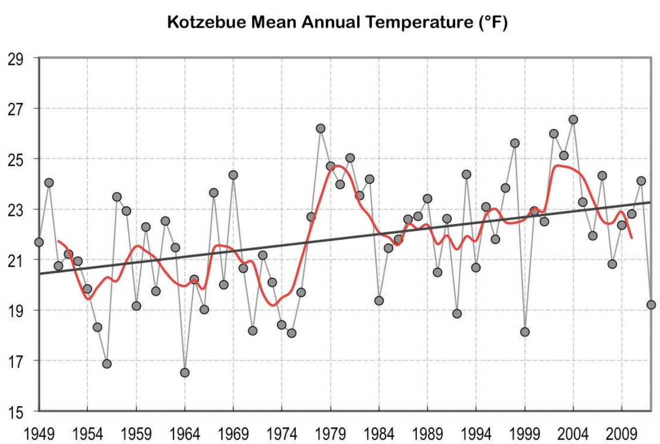

Figure 2. This graph shows that Kotzebue, the regional hub of northwest Alaska, has experienced increasing temperatures over the past four decades. Source: Alaska Climate Research Center, Geophysical Institute, University of Alaska Fairbanks.

Changing Weather

Residents of all three communities perceive winters to be warmer and notice less snow during the winter months than in the past. Interview participants consistently commented that winters are now milder compared to the past and long stretches of severe cold are much shorter in duration. Eighty-five percent of survey respondents agreed that winters are warmer now compared to about 20 to 30 years ago. One person characterized recent winters as "skinny," with warm weather, fewer storms, and low snowfall. Summer weather also appears to be changing, which has implications for water temperature and fish health. Many interview participants cited examples of uncharacteristically warm weather and the presence of soft, mushy fish and even fish die-offs in warm water bodies.

Shifting Break-up and Freeze-up Patterns

Changes in the timing and nature of freeze-up and break-up are viewed as indicators of changes in the overall weather of the region. These two events mark the end of one season and the activities associated with that season, and a transition to another season and its associated activities. In this region, spring break-up is typically preceded by a period of deteriorating ice conditions, followed by an actual ice break-up event that generally occurs over the course of many hours or a full day, and is preceeded by high water levels in local rivers and streams, which is not conducive for fishing. During freeze-up there is a period of limited travel as the formation of heavy slush ice and shore ice curtails boat travel, and people await the formation of ice solid enough to allow safe crossing of local water bodies by overland transport methods. Overall, interview participants notice that break-up is happening early and more quickly and freeze-up is happening later and more slowly, often characterized by an abnormal freeze-thaw cycle. These changes create challenges for subsistence fishing practice. Fast spring break-up limits the amount of time available for ice fishing and creates dangerous travel conditions. A late fall freeze-up creates challenges for traditional fish processing techniques, which require consistently cold temperatures. The following quotes discuss these changes in freeze-up and break-up:

Stuff is starting to change. [Break-up] comes early, comes really suddenly... It used to be a long spring, just melting slowly. Now it won't do that. Everything just melt. The ice rot real quick and crumble… Selawik, July 19, 2010

Last few years it's been unpredictable in the fall time... when we're going to have freeze-up. We think it's finally here and then it melts again. Selawik July 22, 2010

Our weather change from when I was a young kid. When we have break-up here at Noatak, we used to have real high water. Not the way we have right now. That's low water down there. Everything changed. You can see our river right now. It's low water. Noatak June 18, 2010

Lower Water Levels

Residents of these communities constantly monitor water levels of rivers and lakes because they affect both boating and fishing conditions. High water levels are generally not good for fishing because the fish do not generally congregate and are difficult to find. When water levels drop, fish often collect in deep pools along the river channels, making them easier to find and harvest. However, low water levels can serve as a barrier to accessing certain spots by boat. Because water levels play such an important role in subsistence activities, new patterns of water level fluctuations are perceived to be particularly significant phenomena linked to climate change. In all three communities, interview participants consistently noted lower water levels during the open water season. In support of this observation, 89% of survey respondents agreed that river water levels are lower now compared to 20 to 30 years ago. Low water causes much difficulty when boating. We heard about innumerable incidences

Figure 3.

Figure 4.

of boats hitting the bottom and receiving costly damage. People also noted that they are now often unable to reach where they would like to fish because of low water levels.

I think from being too hot last few years, there's less water. We used to be able to boat in and out and [now] we hit ground. We had to pull the motors up and use poles to go back to the main river. Selawik July 22, 2010.

Thawing Permafrost

Thawing permafrost and subsequent erosion is a particularly apparent change detected by residents of northwest Alaska. In the survey, 92% of respondents agreed that permafrost is thawing more now compared to 20-30 years ago and 97% agreed that thawing permafrost affects the land, river banks, and lake edges. The rivers of this region display dramatic evidence of large thaw slumps. The nine-acre wide and eighty-foot high "Selawik Slump," located 175 mi (282 km) upstream from the village of Selawik, is likely the largest in North America (Rozell 2009). It is not yet known how sediment from the expanding slumps may affect spawning habitats for fish.

Increasing Presence of Beaver

In all three communities, we learned that hunters and fishermen are noticing increasing local populations of beaver. In Selawik, one informant noted, "I notice that there's tons of beaver where there hardly used to be beavers around." Another explained, "All over they make dams. There are too many… pretty soon we going to have no more fish." Similarly in Noatak and Shungnak, informants noted that beaver have become increasingly abundant in the area, particularly in the last ten to fifteen years. This increase is likely partly the result of decrease in hunting pressure. However, some informants also relate increasing beaver numbers to warmer weather and increasing vegetation in the region. Many fishermen agree that beaver affect local fish populations. One informant noted that "Beaver are a menace to the fish." Beaver dams have a particularly visible impact, since many people see fish blocked behind beaver dams during periods of low water. Beaver dams also make boating increasing difficulty. The ecological impacts of increasing beaver numbers in northwest Alaska is an area requiring further research.

Conclusions

Active and experienced subsistence harvesters in Noatak, Shungnak, and Selawik consistently note a range of environmental changes linked to climate change, which

Figure 5.

Figure 6.

have implications for current and future subsistence fishing practices. Lower water levels hinder boating access to important fishing locations. Unpredictable weather conditions challenge traditional fish processing methods. Increasingly warm fall temperatures and freeze-thaw cycles create dangerous travel conditions and limit mobility. Beaver have the potential to dramatically reshape the aquatic environment, with implications for fish health and abundance, as well as human health. Overall, we found a high level of agreement, based on cultural consensus analysis, about the observations of environmental shifts between and among Noatak, Shungnak and Selawik expert informants. As climate change research in northern ecosystems continues, it is increasingly important to include the perspectives of local harvesters, who are experiencing these changes firsthand.

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Hidden Creek Glacier, R.D. Karpilo 2004

Denali Repeat Photography Project Reveals Dramatic Changes: A Drier, Woodier, and More Densely Vegetated Park

By Carl A. Roland and Sarah E. Stehn

In 2005 Denali National Park and Preserve received a donation of many hundreds of photographs taken from the backseat of a two-seater airplane by Dr. Fred Dean, emeritus professor of wildlife biology at the University of Alaska. Dr. Dean had taken these photographs in the summers of 1975-6 as part of a project to produce the first land-cover map of (then) Mt. McKinley National Park. This treasure trove of images and associated mapped locations documented by immaculate field notes helped launch a major effort to acquire matched sets of repeated historic/modern photo pairs as a way to observe and detect changes occurring across the park landscape: the Denali Repeat Photography project.

The goals of the Denali Repeat Photography project are to acquire, organize, and interpret matched repeated photographs that capture landscape dynamics as they occur across time, and present them in an informative manner accessible to a diverse audience. To meet these goals, park staff looked far and wide, searching archives and personal collections and working with cooperators including long-time Denali researchers such as Dr. Leslie Viereck to find valuable historical images that would be useful for studying landscape change. Park staff then made numerous trips on foot, by vehicle, or by helicopter to repeat, as closely as possible, the original historical photographs. We also received donations of many high-quality repeated photo-pairs from cooperators such as Ron Karpilo, a geologist who has captured numerous images of glacier change in the park. The results of these wide-ranging efforts over the past eight years are organized and presented in a new website "Exploring Landscape Change Through Repeat Photography" (http://www.nps.gov/dena/naturescience/repeat-photos.htm), showcasing more than 200 matched photo pairs from across Denali with interpretations and background information about the change (or sometimes, the lack thereof) revealed in these images.

The repeat photo pairs provide dramatic visual evidence of recent changes in vegetation, water bodies, and glaciers, among other elements of the landscape. While there are unique natural and cultural history vignettes revealed among this large set of photographs, such as the draining of Bergh Lake, and the burial of the Copper Mountain Cabin by river gravels, the majority of photo pairs show change patterns that appear to be operating on a larger scale. In fact, the magnitude of observed changes in many of these photo pairs suggests that a significant alteration of the parks ecosystems is occurring in some areas, likely caused by a warming climate and related processes. Some of the primary types of change documented include: (1) expansion of spruce into formerly treeless areas, (2) invasion of open wetland areas by woody vegetation, (3) widespread colonization of formerly open floodplains and terraces by vegetation, (4) shrinking ponds, and (5) receding glaciers and related features. In many cases, these changes appear directional; that is, they represent a qualitative shift in the landscape mosaic, not simply a shift in vegetation due to succession or cyclical fluctuations in pond level or glacial extent. The Denali Repeat Photography project has helped to gather and make available to the public this valuable visual evidence of these important and far-reaching changes that have the potential to significantly affect park resources over the long term.

Figure 1. Repeated images of Denali's glaciers reveal the rapid glacial retreat that is changing the face of the park.

Photos courtesy of Stephen Capps and Ron Karpilo

Figure 2. Beginning in 1938 a channel of the Thorofare River gradually buried the Copper Mountain patrol cabin, a testimony to the power of nature to transform the landscape and the human traces upon it.

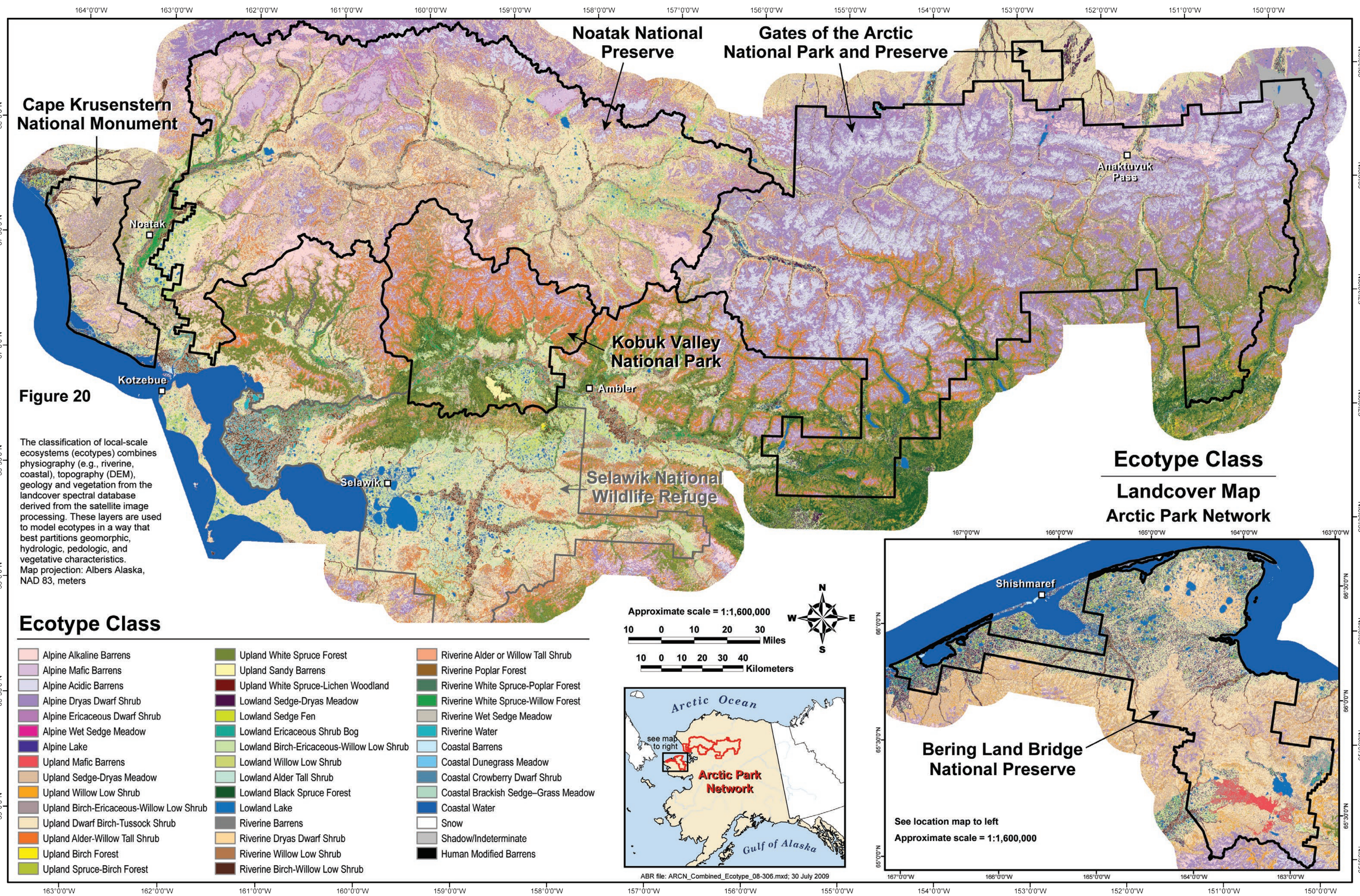


Figure 20

The classification of local-scale ecosystems (ecotypes) combines physiography (e.g., riverine, coastal), topography (DEM), geology and vegetation from the landcover spectral database derived from the satellite image processing. These layers are used to model ecotypes in a way that best partitions geomorphic, hydrologic, pedologic, and vegetative characteristics. Map projection: Albers Alaska, NAD 83, meters

Predicting the Effects of Climate Change on Ecosystems and Wildlife Habitat in Northwest Alaska: Results from the WildCast Project

By Anthony R. DeGange, Bruce G. Marcot, James Lawler, Torre Jorgenson, and Robert Winfree

Abstract

We used a modeling framework and a recent ecological land classification and land cover map to predict how ecosystems and wildlife habitat in northwest Alaska might change in response to increasing temperature. Our results suggest modest increases in forest and tall shrub ecotypes in Northwest Alaska by the end of this century thereby increasing habitat for forest-dwelling and shrub-using birds and mammals. Conversely, we predict declines in several more open low shrub, tussock, and meadow ecotypes favored by many waterbird, shorebird, and small mammal species.

Introduction

The Arctic is changing faster in response to climate warming than other places on earth. But what will this change mean to the ecosystems and wildlife populations that are found in the far north of Alaska? By studying the changes that have already occurred there, we can anticipate how future climate change could affect the plants and animals that make up this unique part of the world.

To address this issue, the WILDlife Potential Habitat ForeCASTing Framework, or WildCast, was begun as a collaboration between the National Park Service and the U.S. Geological Survey to develop a predictive framework for ecosystems and wildlife habitat in Northwest Alaska. The study area includes the five national park units that make up the Arctic Inventory and Monitoring Network: Gates of the Arctic National Park and Preserve, Noatak National Preserve, Kobuk Valley National Park, Cape Krusenstern National Monument, and Bering Land Bridge National Monument, as well as the adjacent Selawik National Wildlife Refuge of the U.S. Fish and Wildlife Service (Figure 1). The basic premise of the project is to develop methods and tools that, in the face of limited data, can be used to better understand how climate change might influence ecosystems and the habitats of birds and mammals that inhabit this arctic landscape. The products from WildCast will enable land managers in Northwest Alaska to visualize potential future changes to lands and resources under their jurisdiction, and to help identify and prioritize management, inventory, monitoring, and research needs. WildCast also complements the cooperative scenario planning efforts in Alaska by the National Park Service and Scenarios Network for Alaska Planning (SNAP) (see Winfree et al. in this issue).

Previously, Marcot (2009) summarized some of the challenges in undertaking a project such as this and discussed modeling approaches that can be used to accommodate the uncertainties that inevitably arise in forecasting future ecological scenarios in a data-poor world. In this contribution, we provide a brief overview of progress on this complex and challenging project.

Figure 1. Extent of the study area encompassing the five units of the National Park Service's Arctic Network and the Selawik National Wildlife Refuge (from Jorgenson et al. 2009).

WildCast Vision and Objectives

WildCast is intended to help anticipate how climate change could affect species, communities, wildlife habitats, and ecosystems in Northwest Alaska over the next century. We have three principal objectives:

1. model probable changes in the areal extent of ecosystem types based on historical changes relative to time and regional air temperature;
2. identify likely changes in percent and total area of wildlife habitats; and
3. facilitate identification of critical research priorities to improve model outcomes.

Methods

At the outset, we planned to base our analyses for WildCast on a limited number of land cover types generated from LandSat imagery. However, the availability of a new ecological land classification and land cover map for our study area (Jorgenson et al. 2009; Figure 1) allowed us to expand our analysis to include 60 vegetation land cover types (hereafter, "ecotypes"). To predict future changes in ecosystem abundance, we used a five-step modeling process. First, we analyzed historic trends in mean annual air temperature for selected weather stations located within or near the study area. Second, we compiled data on historical rates of ecosystem change during the last 30–50 years from previous studies in the region, with particular emphasis on the recent comprehensive analyses for the Arctic National Wildlife Refuge (Jorgenson et al. 2011) and the Arctic Network of National Parks (Swanson

2012). Third, data from the individual studies were averaged and adjusted to develop transition probabilities that encompass all the potential transitions from one ecotype into other ecotypes that could result from differing ecological drivers (e.g., fire, thermokarst, and primary succession). Fourth, the transition probabilities were extrapolated into the future for three time periods 2010–2040, 2040–2070, and 2070–2100 where transition probabilities were held constant for all three periods, and temperature, where past transition probabilities for a 1.8°F (1°C) temperature change found in our temperature analyses were linearly extrapolated to predicted temperature changes of 3.6, 7.2, and 10.8°F (2, 4, and 6°C) for the three future periods, respectively. The predicted future changes in mean annual air temperatures for the region were based on the regional projections for Northwest Alaska from the Scenarios Network for Alaska Planning (www.snap.uaf.edu). Fifth, the changes in ecotypes were calculated using the transition probabilities for each time period and the areas at the end of the previous period as the input for the next period. This produced changes as functions of time (fixed rate), temperature (rapidly increasing rate), and an average of time and temperature.

Comprehensive quantitative information on wildlife-

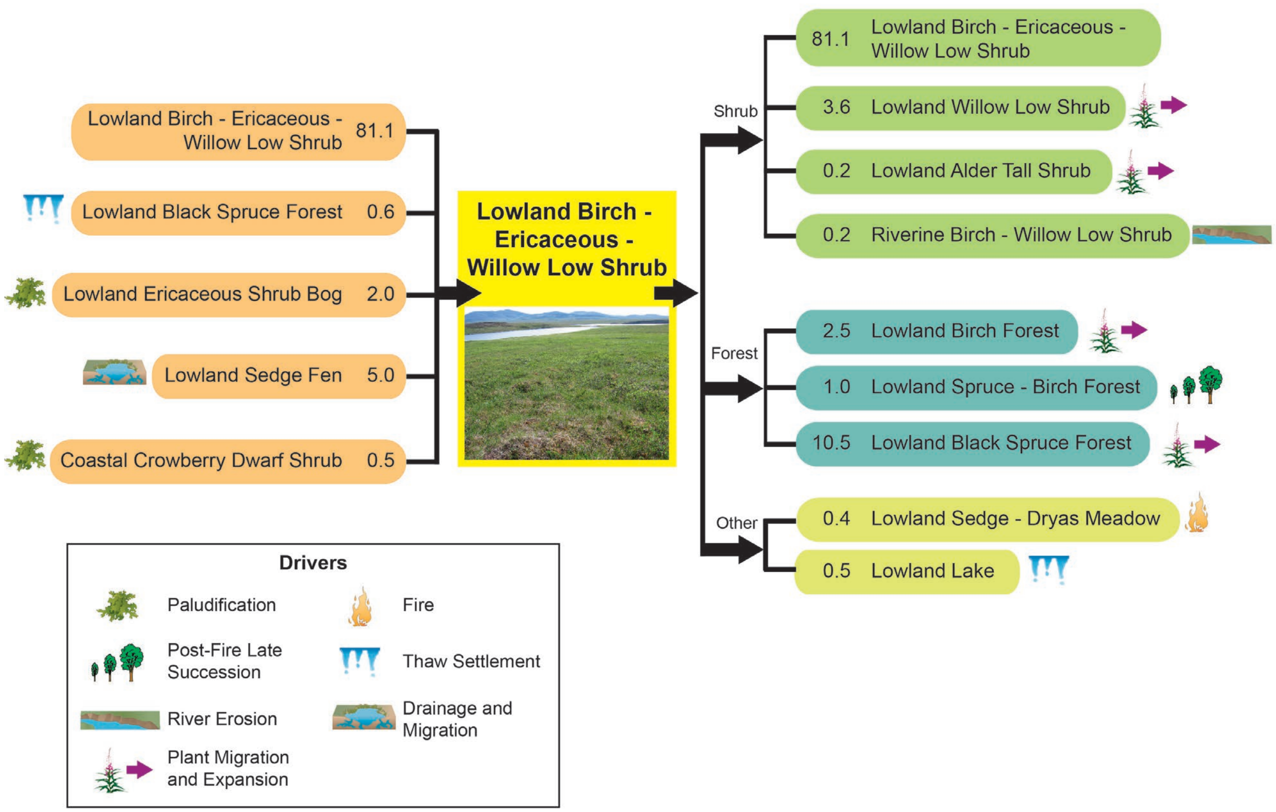
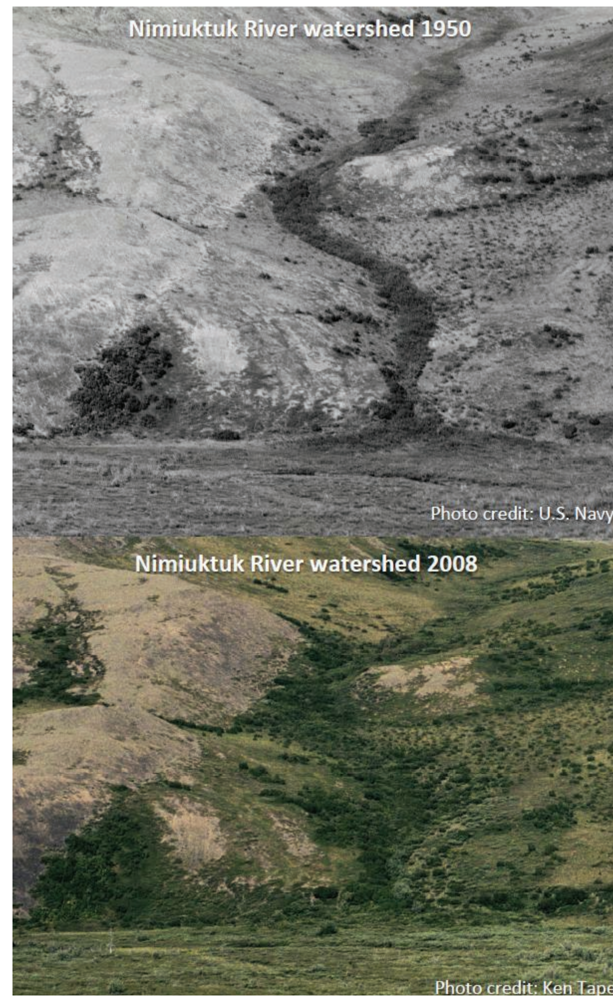


Figure 2. Changes into, and from, one example ecotype, showing 30-year transition probabilities and principle drivers causing the changes. In this example, 5 ecotypes (orange ovals) are expected to remain as, or develop into, Lowland Birch-Ericaceous-Willow Low Shrub (LBLS, yellow square) which, in turn, will remain as, or transition into, 8 other ecotypes (other ovals) due to a variety of drivers. E.g., in 30 years, some 2.0% of existing Lowland Ericaceous Shrub Bog will become LBLS because of paludification, and 10.5% of existing LBLS will become Lowland Black Spruce Forest because of plant migration and expansion. LBLS is important habitat for 17 species of mammals and 13 species of birds.



Photographs courtesy of Ken Tape, University of Alaska Fairbanks

Figure 3. Contemporary ecosystem change in Noatak National Preserve. In this example, Upland Sedge-Dryas Meadow is transitioning into Upland Alder-Willow Shrub.

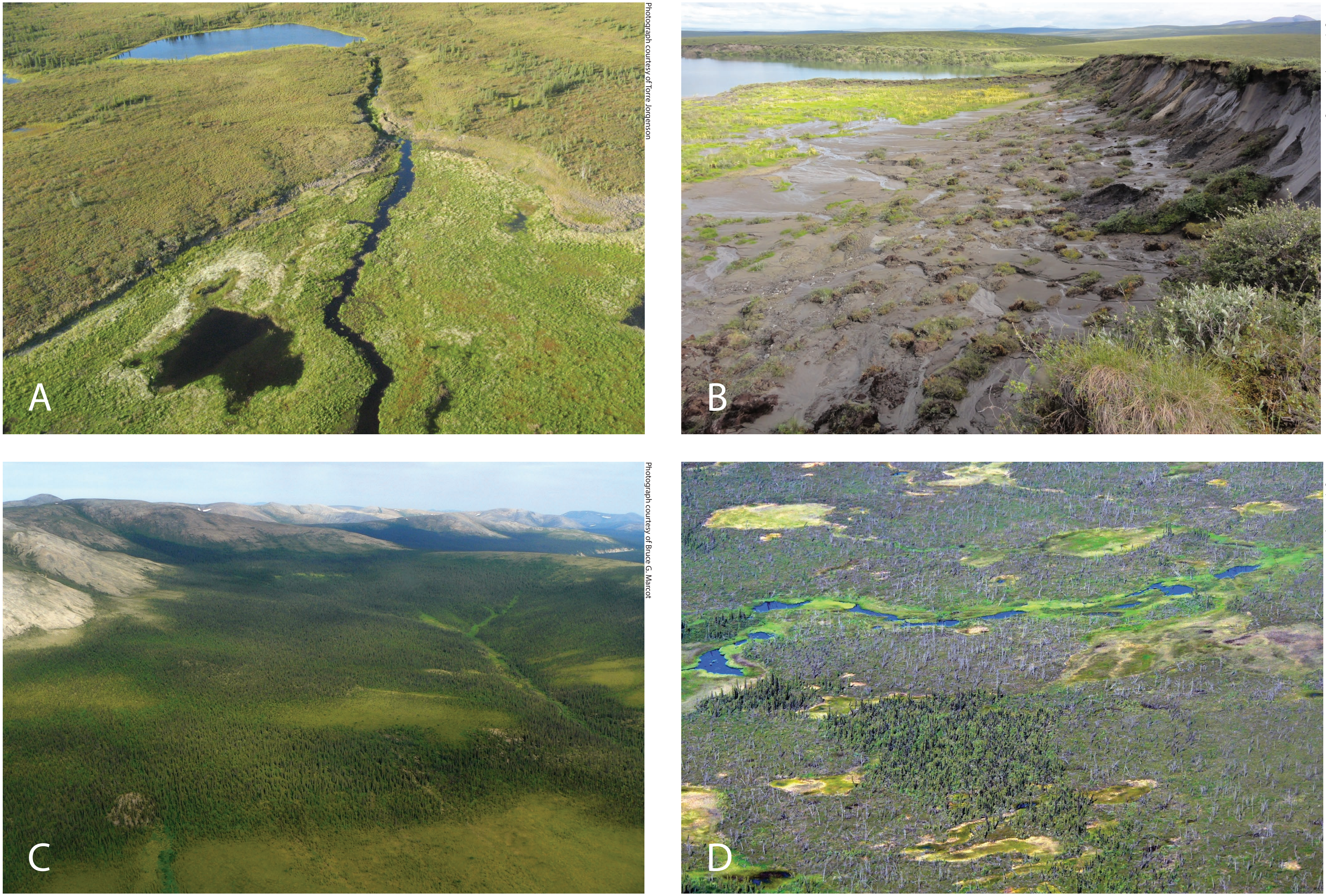


Figure 4. Examples of ecosystem drivers that result in transitions of one ecotype in another into Northwest Alaska: (a) lake drainage; (b) thermokarst thaw slumps; (c) spruce forest expansion; and (d) post-fire succession.

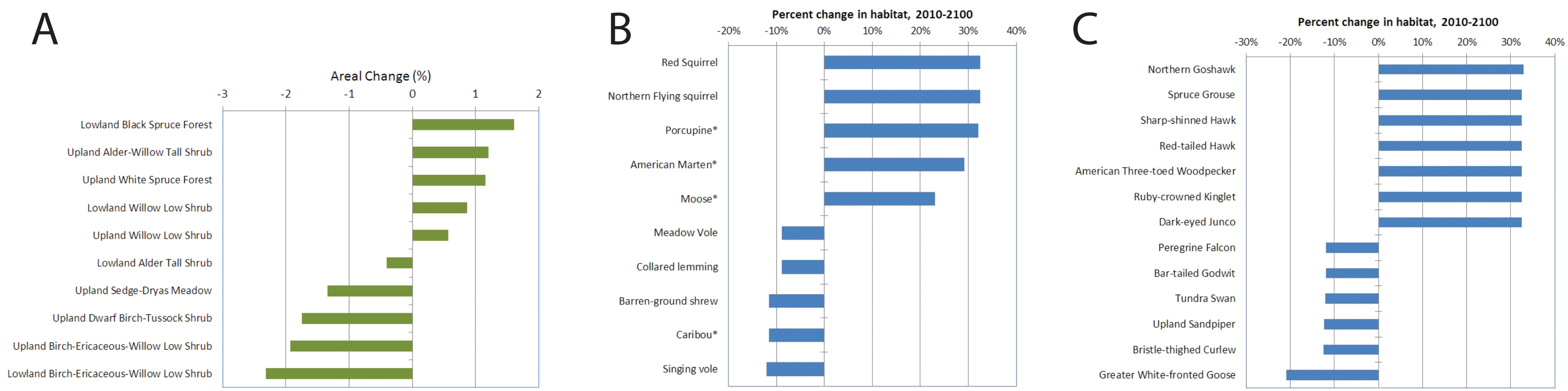


Figure 5. (a) Ecotypes of the Arctic Network (ARCN) projected to gain or lose the most area relative to the entire ARCN area. (b) Mammals and (c) birds of the Arctic Network (ARCN) whose habitat is projected to increase or decrease the most over this century. Shown are species whose habitats currently comprise at least 10% of ARCN.

habitat associations is unavailable for most mammal and bird species that reside in the study area. We recognized this critical data gap, but still needed some way to link species to the ecotypes they live in. Thus, we expanded on an approach used by The Nature Conservancy (TNC) for the North Slope of Alaska. We denoted habitat use of each ecotype by each species on an ordinal scale of 0 (none/negligible), 1 (low), 2 (medium), and 3 (high use) based on a qualitative synthesis of available data. To ensure that TNC's approach was transferable to our study area, we cross walked and embellished their list of ecotypes to those from Jorgensen et al. (2009), and added species that occur in Northwest Alaska. Because our study projects future points in time, we added species that currently occur near, but not within, the study area, but that might move in if suitable habitat exists there sometime in the future. Species experts provided and reviewed our bird and mammal habitat use assignments. Next, total habitat area for each species was determined by tallying associated ecotypes, for each time period. In this way, we identified individual ecotypes, and species-specific habitats with significant gains and losses in extent within the study area, under historic temperature change rates extrapolated into the future. Our model provides a framework for easily updating any of the parameters for conducting sensitivity analyses or for incorporating improvements or variants in any of the parameter values such as different future temperature scenarios.

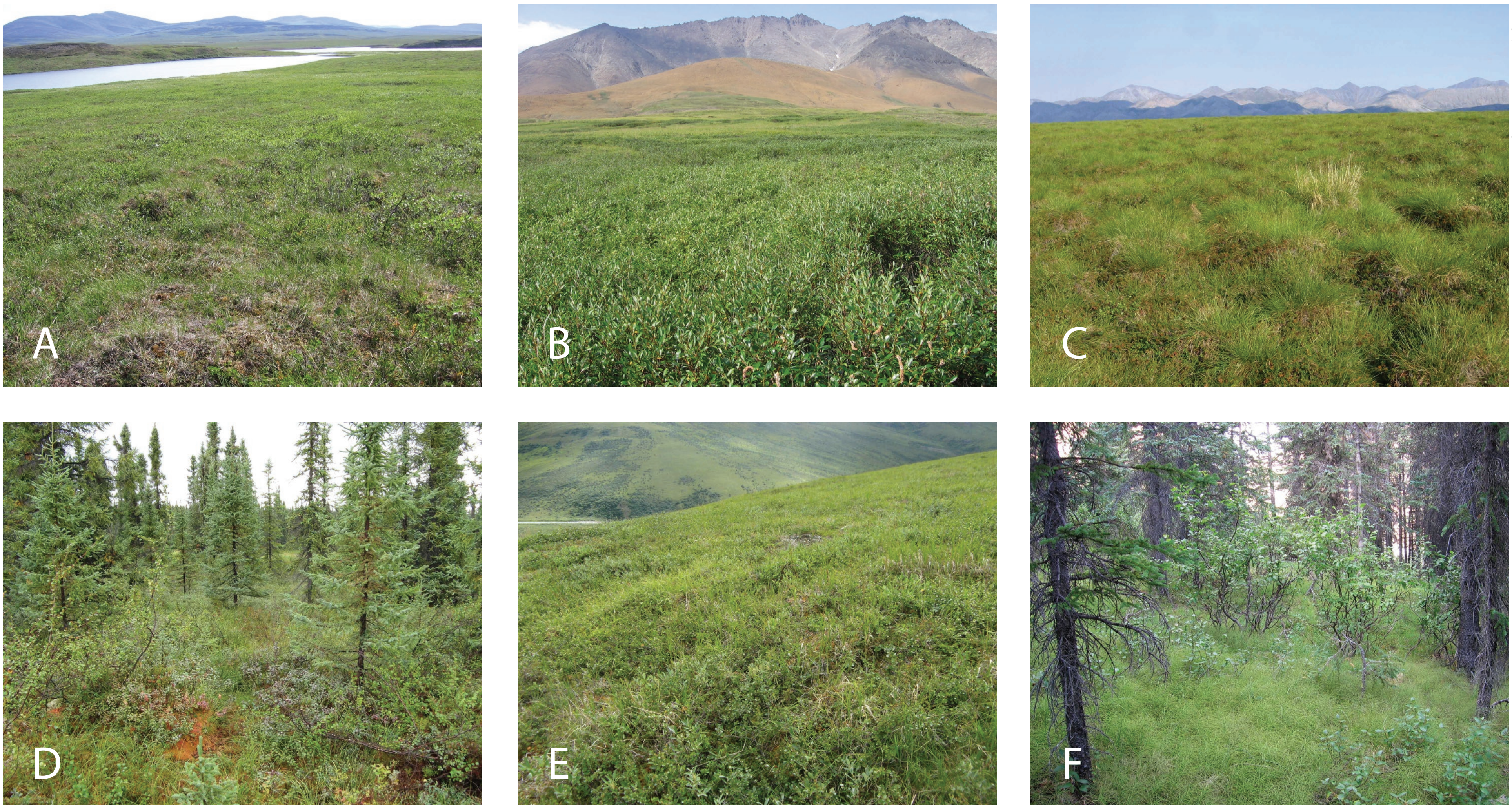
Results

Changes in Ecotypes

Future ecological transitions are based on 60 ecotypes found within the study area. We identified 243 potential ecological transitions that involve changes from one ecotype into another due to geomorphic and ecological processes that are likely to be influenced by climate change. A summary of key findings follows below, with detail on additional ecotypes and species provided in forthcoming publications. A few ecotypes show only one reasonable transition possibility (staying the same, e.g. from Alpine Lake to Alpine Lake), while others showed more. For example, Upland Dwarf Birch-Tussock Shrub showed the maximum number, with 11 potential transitions, due to the numerous drivers that can affect change. Figure 2 illustrates how multiple ecotypes can potentially transition into a single ecotype (in this example Lowland Birch-Ericaceous-Willow Low Shrub), which then can transition into other ecotypes depending on differing ecological drivers. Over a century-long period, an area can be affected by multiple drivers; for example Upland Dwarf Birch-Tussock Shrub can be replaced by Upland Barrens-Thermokarst, then by Upland Alder-Willow Tall Shrub (early succession), and finally by Upland White Spruce Forest (late succession).

Transitions from one ecotype into another have been documented for many ecotypes in Northwest Alaska and other parts of the Arctic (Figures 3 and 4). Based on a comprehensive compilation of data on historical rates of change, our work shows that nearly all ecotypes (56 of 60) will undergo some change in area during the next century across the study area. Ecotypes that currently occupy large areas (>657.37 sq mi or 1,700 km^2) that are likely to experience major losses in area include Upland Birch-Ericaceous-Willow Low Shrub (due to thermokarst, fires, and shrub and forest expansion), Lowland Birch-Ericaceous-Willow Low Shrub (post-fire succession and forest expansion), Upland Dwarf Birch-Tussock Shrub (thermokarst, fires, and shrub and forest expansion), Upland Sedge-Dryas Meadow (thermokarst, shrub expansion, and acidification), and Lowland Alder Tall Shrub (forest expansion)(Figure 5a; also see Figures 6a-c). Conversely, ecotypes that are likely to show major increases include Lowland Black Spruce Forest (forest expansion and post-fire succession), Upland Alder-Willow Tall Shrub (shrub expansion), Lowland Willow Low Shrub (shrub expansion and soil drainage), Upland White Spruce Forest (forest expansion), and Upland Willow Low Shrub (primary succession after thermokarst)(Figure 5a; also see Figures 6d-f).

Several ecotypes that now cover relatively small areas show potential for large future increases when calculated as a percentage of their current areas, including: Upland Bluejoint-Herb Meadow (due to fires), Lowland Birch Forest (thermokarst, fires), Upland Aspen Forest (warming south-facing slopes), Upland Barrens-Thermokarst, Lacustrine Willow Shrub (lake drainage), and Lacustrine Barrens (lake drainage). Conversely, other Ecotypes show potential for large percentage reductions, including: Riverine Dryas Dwarf Shrub (shrub expansion), Upland Birch Forest (post-fire late succession), Upland Barrens-Landslides (early succession), and Alpine Snowfields and Glaciers (melting).



Photographs courtesy of Torre Jorgenson

Figure 6. Examples of ecotypes of the Arctic Network (ARCN) projected to lose or gain the most area relative to the entire study area: Losers – Lowland Birch-Ericaceous-Willow Low Shrub (a), Upland Birch-Ericaceous-Willow Low Shrub (b), Upland Dwarf Birch-Tussock Shrub (c); Gainers - Lowland Black Spruce Forest (d), Lowland Willow Low Shrub (e), Upland White Spruce Forest (f).

Changes in Wildlife Habitat

We assessed potential future changes in the habitat of 36 mammal species and 162 bird species based on medium and high use levels.

The largest percentage habitat gains for mammals through this century are for species that live in forests or use shrubs, including red squirrel, northern flying squirrel, porcupine, American marten, and moose, with gains in overall habitat area for these species exceeding 20%, and with lesser gains for black bear and northern bog lemming. Nearly all other mammals show various levels of decline in habitat ranging up to about 12% loss by the end of the century (Figure 5b), largely due to expected decline in Lowland Alder Tall Shrub, Lowland Birch-Ericaceous-Willow Low Shrub, Riverine Dryas Dwarf Shrub, Upland Birch Forest, Upland Birch-Ericaceous-Willow Low Shrub, and Upland Sedge-Dryas Meadow. Of note is the potential decline in habitats of Alaska hares, ground squirrels, lemmings, voles, and shrews, comprising the set of small mammal prey species important to mesocarnivores of the region, habitat for which is also projected to decline. Among all 36 mammal species analyzed, seven show an increase in habitat area, 28 a decrease, and one with no change.

Many waterbird species show various percentage increases in habitat, with shorebirds being about equally divided among those showing increases and decreases, and many forest- or shrub-dwelling raptors, passerines, and others showing large percentage increases exceeding 30% (Figure 5c). Among the greatest losers is a mix of waterbirds, shorebirds, and raptors, mostly because of expected declines in Coastal Brackish Sedge–Grass Meadow, Lowland Birch-Ericaceous-Willow Low Shrub, Lowland Lake, Riverine Dryas Dwarf Shrub, and Upland Sedge-Dryas Meadow. Among all 162 bird species analyzed, 99 show an increase in habitat area, 59 a decrease, and 4 show no change.

Also considered are wildlife species not currently present but that might move northward into and expand within the study area under future increases in some ecotypes. These include meadow jumping mouse, hairy woodpecker, red-breasted nuthatch, and ruffed grouse.

Key Assumptions and Uncertainties

Our projections of ecotypes are based on the linear extrapolation of historical rates to future time periods based on time (rates stay constant for each 30-yr period) or temperature (using predicted increases relative to historical temperature increase), using published studies of past changes and expert knowledge to forecast rates of future transitions. While the predictions are based on substantial observational records of past changes, there are numerous factors that affect the accuracy of the predictions. First, errors in the classification of

Figure 7. Birds and mammals whose habitat is projected to be positively (top) and negatively (bottom) influenced by climate change in Northwest Alaska: (a) moose, (b) ruby-crowned kinglet, (c) bar-tailed godwit, and (d) bristle-thighed curlew.

ecotypes can occur with both the change detection interpretation conducted from these published studies and with the ecotype map for the study area (Jorgenson et al. 2009) that serve as the basis for quantifying the initial extent of ecotypes. The classification accuracy typically is 80% for photo-interpreted studies and the classification accuracy of the ecotype map was estimated to be between 65-80% for 41 ecotypes, indicating there is substantial error associated with detecting and mapping change. Second, while transition probabilities for the common ecotypes are supported by previous research, the transitions for uncommon types frequently relied on expert opinion. These transition probabilities are derived, in part, from other regions of Alaska and may vary in their applicability to our study area. Third, we recognize that other facets of climate change, such as changes in annual and seasonal precipitation, are also expected to force ecosystem changes. Finally, it is important to note that ecotypes, in themselves, do not respond to the environment, but are comprised of assemblages of species that respond individually to stressors and environmental change. The ecotype classification system is directed at identifying change in the dominant species that are used to characterize the ecotypes. Changes in dominant species during forest succession differentiated by the classification system can also capture some of the changes in other species, because understory species often are associated with dominant species in the canopy. Furthermore, large changes in the environment, such as from lake to barren drained-lake basin, can cause wholesale shifts closely associated plant assemblages.

The wildlife habitat projections are based on the assumption that use of individual ecotypes by a species is independent and equivalent; that is, we do not denote type of use (e.g., for breeding, feeding, resting, or migration) nor how the quality and spatial patterns of habitats contribute to population persistence, mostly because such data do not yet exist. The wildlife species-habitat relationships for Northwest Alaska were based on a combination of expert knowledge and limited field surveys. Our wildlife habitat projections should not be interpreted as expected changes in population size or trend of each species, which would require as-yet unavailable demographic data. We also recognize that availability of potentially suitable habitat does not ensure that it will be occupied, as human-caused disturbances and other factors also influence wildlife distributions.

Conclusions

This is the first evaluation of its type for boreal and tundra ecosystems that provides a comprehensive assessment involving the full diversity of ecosystems across a broad region. Overall, we view the results as a valuable tool for posing testable hypotheses of changes in ecotypes and species' habitats; as a means of identifying potential priorities for management, inventory, monitoring, and research activities; and as basis for improvement over time as new data become available.

Acknowledgments

This project was the outcome of discussions among Leslie Holland-Bartels, Carl Markon, and Robert Winfree on how climate change might affect the natural resources of Alaska's pational parks. Janet Jorgenson, U.S. Fish and Wildlife Service, and Dave Swanson, National Park Service, generously shared their change detection data for the Arctic National Wildlife Refuge and the Arctic Network of National Parks, respectively. We thank Colleen Handel, Andrew Hope, Dave Gustine, Link Olson, and Dan Ruthrauff for reviewing our bird and mammal ecotype use associations. Carl Roland and John Pearce provided helpful reviews of this manuscript. This project was funded through the Natural Resources Preservation Program (NRPP) of the USGS's Ecosystems Mission Area.

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Climate Change Scenario Planning Lessons from Alaska

By Robert Winfree, Bud Rice, John Morris, Jeff Mow, Don Callaway, Don Weeks, Nancy Fresco, and Lena Krutikov

Scenario planning is a tool that enables us to test our assumptions about the future. Scenarios are not forecasts or predictions about the future, but are plausible hypotheses of what could happen. Whereas other planning tools are available for situations of fairly high certainty or controllability, scenario planning is ideally suited for assessing situations with critical and uncontrollable uncertainties, which abound in Alaska. In Alaska, scenario planning has recently been applied to questions about marine shipping, climate change, and port site selection, and soon will be applied to resource development on the North Slope. In this article, we will reflect back on the experience of six National Park Service scenario planning workshops that focused on climate change in Alaska.

Approaches to scenario planning can vary, but these five steps are common:

- Framing the issue, purpose, and scope
- Assessing the available information (including driving forces and critical uncertainties)
- Developing and evaluating plausible scenarios (including potential effects and implications)
- Planning and implementing appropriate actions, and
- Monitoring the indicators and consequences of change

Figure 1. Sheet flooding of Exit Glacier Road is a new thaw-related phenomenon for managers at Kenai Fjords National Park.

NPS photo by Jim Pfeffinberger

We were looking at climate change in parks, so we framed the issue with two questions.

- How will climate change impact the landscapes within which the parks are placed over the next 25 to 100 years, and then
- How can managers best preserve the natural and cultural resources and other values within their jurisdiction in the face of climate change?

More than 140 people from 25 agencies, institutions, and communities participated in one or more of the workshops that were jointly organized by NPS and the Scenarios Network for Alaska Planning (SNAP), with funding and technical support by the NPS national Climate Change Response Program. The implications and recommendations that are identified through scenario planning can be influenced by who participates in the process. To promote information sharing and broader perspectives, we deliberately set aside about half of the seats in the workshops for people outside the NPS, including other agencies, park-affiliated communities, businesses, and nongovernment organizations. We didn't pre-select for people who already accepted the evidence for climate change—some didn't, but we provided all workshop participants with background on the subject, through a series of presentations and selected readings. Within NPS, about 80% of the participants worked in five career fields: Natural Resources and Inventory & Monitoring, Interpretation & Education, Management, Planning & Compliance, and Cultural Resources. Other participants came from the fields of Fire, Maintenance, Subsistence, Protection, Wilderness, Social Science, GIS, and Concessions, although not all fields were represented at every workshop, perhaps reflecting an assumption that climate change is primarily a natural resources and science issue.

Developing the scenarios started with identifying two scenario drivers—factors of high importance and high uncertainty that participants felt could strongly influence future conditions in and around the parks. Table 1 shows the drivers that were ultimately selected by ten groups, each of which developed two scenarios. The selected drivers included temperature and precipitation, storm activity, and for marine scenarios, ocean acidification. Participants discussed potential effects of changing climates, social and institutional responses, creating four plausible, relevant, divergent and challenging scenarios during each 3-day workshop. We chose to focus these scenarios on conditions that could occur 20-30 years from now, far enough to get beyond short-term climatic variations (such as the Pacific Decadal and Arctic Oscillations), but close enough to still be relevant to park staff or to their successors. Although this report will not delve into the methodology or the specific scenarios in detail, that information is contained in other reports and presentations on the project web site: http://www.nps.gov/akso/nature/climate/scenario.cfm

We focus here on a summary of more than 750 implications and recommendations that were identified through this process. With 20 widely divergent scenarios, from 10 groups, in 5 workshops, across the state of Alaska, we might expect that the implications and recommended actions would also be highly divergent. There were implications that were specific to particular scenarios, but there was also a lot of similar thinking across a very wide range of scenarios. About a third of the implications focused on general environmental changes. Listed in declining order by the number of implications identified, these included impacts related to: cultural sites, invasive and pest species, water supplies, fire hazards, biodiversity, permafrost, habitats (see DeGange et al. in this issue), glaciers, ice loss, contaminants, vegetation, and higher or lower relative sea level change – both of which we're seeing in different parts of Alaska.

Fundamental environmental changes would also have implications for wildlife and fish, and for subsistence access, all of which are major food security concerns in Alaska. Facility and infrastructure failures were also identified in many scenarios, such as damaged foundations, roads and utilities (Figure 1) and a growing need for sustainable energy supplies and use (Figure 2). Regional economic development, especially from minerals, energy, and transportation—related activities, were considered likely—with potential benefits and risks.

Nearly a quarter of the implications were related to current and potential effects on communities: due largely to changes in subsistence foods (also see Moerlin et al. in this issue), facilities and infrastructure (Figure 3) (also see Rice et al. in this issue), and needed services. The tourism industry was under-represented in several workshops, which may account for the relatively few implications related to changes in tourism, or to the agency's ability to handle those changes. However, there were more questions about the agency's ability to remain relevant, protecting people and resources in a rapidly changing environment (Figure 4).

Although climate change is expected to have some benefits, only about 5% of the implications were phrased in neutral or favorable terms. Potential benefits from some scenarios and perspectives included more roads, tourism, berries, moose, bears, and beaver—and locally-new wildlife species like deer, elk, cougar and bison (Figure 5). Perhaps the tendency to identify negative implications stems from concern that resources and people that are already well adapted to current conditions may not fare as well if conditions change.

About 3-4% of the implications actually stemmed from actions that people could plausibly take to adapt

Drivers / Scenario Workgroup	Atmospheric Carbon Dioxide	Air Temperature	Precipitation	Atmospheric Circulation
Northwest AK Bering Land Bridge		Temperature	Extreme Precipitation and Storm Events (includes wave action)	
Northwest AK Cape Krusenstern		Temperature		Extreme Storm Events (includes wave action)
Southwest AK Coastal Group	Ocean Acidification		Storms/Precipitation (includes wave action)	
Southwest AK Riverine Group		Thaw Days	Precipitation	
Southeast AK Marine Group	Ocean Acidification	Stream Flow		
Southeast AK Terrestrial Group		Seasonality of Water Flow	Extreme Events (storms, floods, fires, etc.)	
Central AK Wrangell-St. Elias and Yukon-Charley Rivers		Season Length Above-Freezing	Water Availability	
Central AK Denali		Season Length Above-Freezing	Precipitation	
Interior Arctic AK Group 1		Changes in Seasonal Timing (phenology)	Extreme Events (storms, floods, fires, etc.)	
Interior Arctic AK Group 2		Temperature	Precipitation	
Total	2	9	8	5

Table 1. These climate drivers that were selected by ten workgroups, each of which developed two scenarios. Most groups selected drivers that were related to temperature, precipitation, atmospheric circulation (storms), or ocean acidification.

More Intensive Wildlife Management
More Predator Control
Moose "Farming"
More Reindeer Herding
More Hunting Restrictions
More "Proxy" Hunters and Fishers
More Fish Hatcheries
Co-Management of Resources
Innovative Modes of Tourism

Table 2. Adapting to climate-related changes could also have implications to other resources and values.

Figure 2. Mitigating fossil fuel consumption with an NPS solar power system at Bettles, Alaska.

to other changes. While small in number, some of these implications could be very challenging for Alaskan park managers—and some already are (Table 2).

Among recommended management actions (Figure 6), building partnerships was mentioned more than anything else—partnerships with local communities, tribes, other agencies, and cross-borders, with Canada and Russia. Using sustainable facilities, energy sources and practices was also very high among the recommendations, as was improving our capacity for dealing with larger and more frequent emergencies, like fires, flooding, spills, and other disasters (Figure 7), and improving our ability to communicate with multiple audiences.

We can also build climate change and scenarios thinking into our planning processes. Scenarios are a "wind tunnel" for testing management strategies, proposed actions, and NEPA planning alternatives against broad range of plausible futures – including those that are beyond current mindsets. Scenarios enable us to ask the question "Would this approach make sense if conditions are different in the future... and if not, is the investment worth the risk?"

Acquiring needed information and developing the capacity to use it is another kind of "no regrets" action. Two-thirds of the identified information needs related to resource monitoring, reflecting active participation by people concerned about natural,

NPS photo by Bob Winfree

Figure 3. Increased wave activity and reduced ice cover has caused severe coastal erosion at Bering Land Bridge National Monument and the community of Shishmaref.

NPS photo by Josh Foreman

Figure 4. Workshop participants expressed concerns about the abilities of agencies to remain relevant in a rapidly changing future.

cultural, and subsistence resources. More monitoring of wildlife and habitat, and expanded monitoring in general, were mentioned most frequently. Monitoring of water supplies, cultural resources, and traditional knowledge was also mentioned frequently (Figure 8).

In Alaska, with our highly dispersed parks and communities, limited transportation and communications alternatives, climate change represents serious challenges for park resources, facilities, operations, and stakeholders. Impacts to rural and park-affiliated communities weighed high among these identified concerns, as did agencies' abilities to protect people and resources in a changing environment. Scenario planning is not prescriptive. It doesn't set or determine policy. However, it does offer useful information for policymakers, land managers, and stakeholders as they face the task of planning for an uncertain future.

The President of the United States recently identified fostering of partnerships, stakeholder engagement, and research for science-informed decision as key elements of his National Strategy for the Arctic Region (Obama 2013). The Interagency Working Group's Report to the President (IWG 2013) expanded on these ideas, and identified scenarios as a promising planning approach. This scenario planning process does not end with the workshops, reports and presentations. Rather, these

NPS photo by Robert Winfree

Figure 5. Potential benefits suggested by some scenarios and perspectives, included more roads, tourism, berries, moose, bears, and beaver and locally-new wildlife species such as deer, elk, cougar, and bison (shown here).

Figure 6. Among recommended management actions, building partnerships was mentioned more than anything else – partnerships with local communities, tribes, other agencies, and cross-borders, with Canada and Russia.

NPS photograph

Figure 7. Increasing transportation and changing marine hazards were among the concerns mentioned relative to emergency response capacity. This ship grounded on glacial outwash sediments in Glacier Bay National Park.

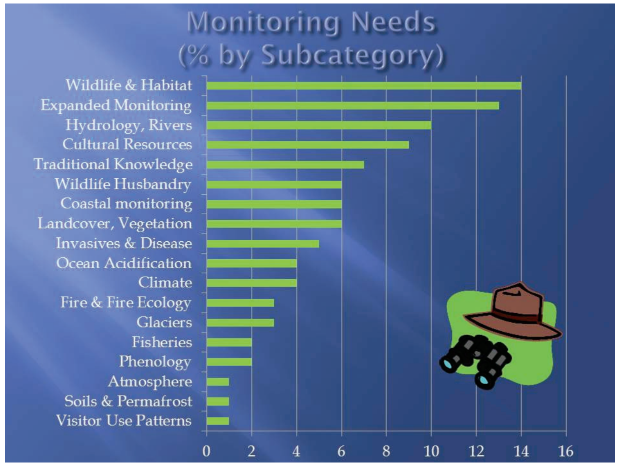

Figure 8. Acquiring needed information and developing the capacity to use it is another kind of "no regrets" action. Increased resource monitoring, to better understand changing systems, was recommended in all workshops.

are intended to stimulate creative thinking, to address changing, but still undetermined future conditions.

Long-term monitoring and feedback to the scenarios process are also important. New and unexpected information may warrant revisiting these scenarios or repeating the process later. Good and consistent communications are vital for policymakers, land managers, and stakeholders as they face the task of planning for uncertain and challenging futures. Scenarios thinking can help them prepare, and lessen the element of surprise. Potentially, some of the most useful outcomes from this project will be development of a suite of tools to communicate climate change impacts, choices, and potential outcomes to a wide range of stakeholders. Change is nearly always stressful, because the things we've become accustomed to are no longer the same, and we need to adapt to the differences. However, people, organizations, and ecosystems do adapt, and people can choose to make the future different.

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Final reports, presentations and other information is available for each of the workshops. That information is contained in other reports and presentations on the project web site: http://www.nps.gov/akso/nature/climate/scenario.cfm


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Influence of Climate Change on Geohazards in Alaskan Parks

By Marten Geertsema, John J. Clague, and
Andreas Hasler

Introduction

Alaska's Southeast parks are among the most impressive in the world. Cold lofty peaks, valley glaciers, and ice fields back verdant Sitka spruce forests along the fjord-incised coast, with forests of the smaller white spruce inland. The parks are situated on the Pacific Rim of Fire, a necklace of volcanoes and earthquake-prone ground at the margin of the Pacific Plate. Earthquakes, active volcanoes, and steep slopes are the ingredients for large landslides, and river floods and tsunami are frequent in this landscape. The coastal region is battered by Pacific storms, which further act on these slopes, priming and conditioning them for failure over decades, centuries, and millennia.

Although climatically diverse, Alaska is likely to experience an overall increase in temperatures through this century, especially in winter, and winters are likely to become wetter and summers drier (USGRP 2009). Landscape responses to these climate changes will be complex. Increased snow loads can influence glacier dynamics, trigger landslides during rapid melt, and cause flooding. Intense rainstorms can trigger shallow landslides.

Two longer term consequences of climate warming that will affect slope stability are glacier thinning and permafrost degradation. Changes to glaciers are easy to recognize. Trim lines and lateral moraines benchmark the limits of previous larger extents (Figure 1). Time lapse photography and spectacular videos of calving glaciers into tidewater attest to the dynamic nature of glaciers as slow rivers of ice. Permafrost degradation is less obvious, but more insidious. You cannot tell just by looking at a steep rock face whether or not permafrost is present.

Figure 1. Prominent trimlines (arrows) delineate previous margin of Llewellyn Glacier, an outlet glacier of the Juneau Icefield.

Influence of glaciers on slope stability

Glaciers have strong effects on the stability of slopes. They erode, redistribute and deposit soil. Sediment exposed during glacier retreat is temporarily unvegetated and often draped over steep slopes and thus vulnerable to debris slides and flows (Huggel et al. 2012).

Valley glaciers condition rock masses for failure in four main ways (Geertsema and Chiarle 2013). First, they erode and deepen valleys and steepen valley walls. Second, flowing glacier ice exerts stresses on valley floors and walls and can fracture bedrock. Third, as glaciers thin and retreat, support is removed—slopes are 'debutressed'. Fourth, relaxation of glacier-induced stresses results in the widening of fractures and joints, conditioning the slopes for mass movement (Figure 2).

Glaciers that hang on steep rock faces and firn or ice on ridges and summits are potential sources of ice avalanches; they also affect the stability of the underlying rock (Fischer et al. 2013). A reduction in the extent of snow and ice on steep slopes at high elevation exposes fresh rock to strong temperature cycles. Mechanical loading due to more and wetter seasonal snow fall may also destabilize some steep alpine slopes. Enhanced warming of firn and alpine permafrost in a warmer climate is another destabilizing influence (see below). More meltwater will reach potential failure surfaces via fractures and clefts in rock.

We recognize three main categories of mass movement on glacially conditioned rock slopes: rock fall, deep-seated slope deformation, and catastrophic rock avalanches. Rock fall rates are high on steep slopes in fractured rock and on recently deglaciated cirque headwalls (Fischer et al. 2013). Rates are lower on slopes that have been exposed for longer periods. Glacial debuttressing since the Little Ice Age may also cause deep-seated rock sagging in mountains, a process known as "sackung". Slow sagging of rock slopes may continue indefinitely, for centuries or millennia, but in some instances can lead to catastrophic slope failure. A large, slowly sagging slope (Figure 3) in Glacier Bay National Park has been studied by Wieczorek et al. (2007). If it were to fail catastrophically, the rock mass would enter the Tidal Inlet and produce a large and potentially destructive displacement wave. Glacial debuttressing may also be one of the factors responsible for large-volume, long-runout landslides known as rock avalanches, which are characterized by a streaming behavior. A combined rock and ice avalanche from Lituya Mountain in 2012 travelled more than 5 miles (8 km) over a glacier (Figure 4; Geertsema 2012).

Outburst floods from lakes dammed by glaciers and moraines

Many glaciers in Alaska parks impound large bodies of water that may drain suddenly, causing downvalley floods, termed jökulhlaups (Figure 5). These floods are far larger than normal nival and rainfall-triggered floods (Costa and Schuster 1988; Clague and Evans 1994; Loso et al., this volume). The water bodies exist on top of, within, beneath, or at the margins of glaciers. Those are the margins of alpine glaciers are commonly the most prone to draining, especially if located in trunk valleys at the toes of glaciers flowing out of tributary valleys,

Glacial lakes may drain suddenly and unexpectedly following a long period of stability due to progressive wastage of the glacier dam (Costa and Schuster 1988; Clague and Evans, 1994). Sudden draining of these lakes typically happens due to rapid development of subglacial channels that serve as conduits for outflowing water. Glacier dams may also fail by collapse following rapid glacier advances (surges) that block streams for only months.

Lakes also developed behind Little Ice Age end moraines as glaciers retreated in the late 19th and early 20th centuries (Costa and Schuster 1988; O'Connor and Costa 1993; Clague and Evans 1994, 2000). Many of these moraine dams are unstable and vulnerable to failure (Figure 6) because they are steep-sided and consist of loose sediment. Irreversible rapid incision of the dam may be caused by a large overflow triggered by an ice avalanche or a rock fall. Other failure mechanisms include earthquakes, slow melt of buried ice, and removal of fine sediment from the dam (piping).

Floods resulting from failures of glacier and moraine dams may transform into debris flows as they travel down steep valleys (Clague and Evans 2000). Entrainment of sediment and woody plant debris by floodwaters may cause peak discharge to increase downvalley, with a potential increase in travel distance and destructiveness.

Outburst floods from lakes dammed by glaciers and moraines erode, transport, and deposit huge amounts of sediment over distances of tens of kilometers. They alter river floodplains tens of kilometers from the flood source. They broaden floodplains, destroy pre-flood channels, and create a new multi-channel, braided planform. The changes can persist for decades after the flood, although rivers quickly reestablish their pre-flood grades by incising the flood deposits.

Degradation of mountain permafrost

Permafrost is widespread in Alaska, both at lower elevations in the northern part of the state and in high mountains. Periglacial features such as stone stripes, rock glaciers, solifluction lobes, and palsas attest to its presence. It is now recognized that the degradation of mountain permafrost in our warming climate is contributing to an increase in landslides (Geertsema et al.

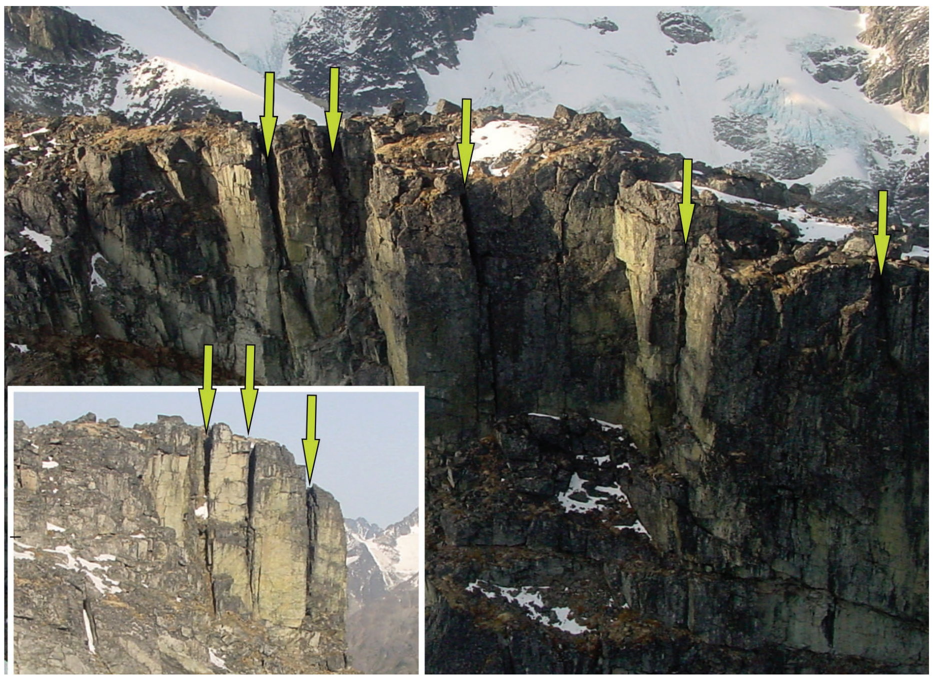


Figure 2. Glaciers erode valleys and steepen valley walls. When they leave the valleys, a lowering of stress may result in joint expansion, priming slopes for collapse (Marten Geertsema).

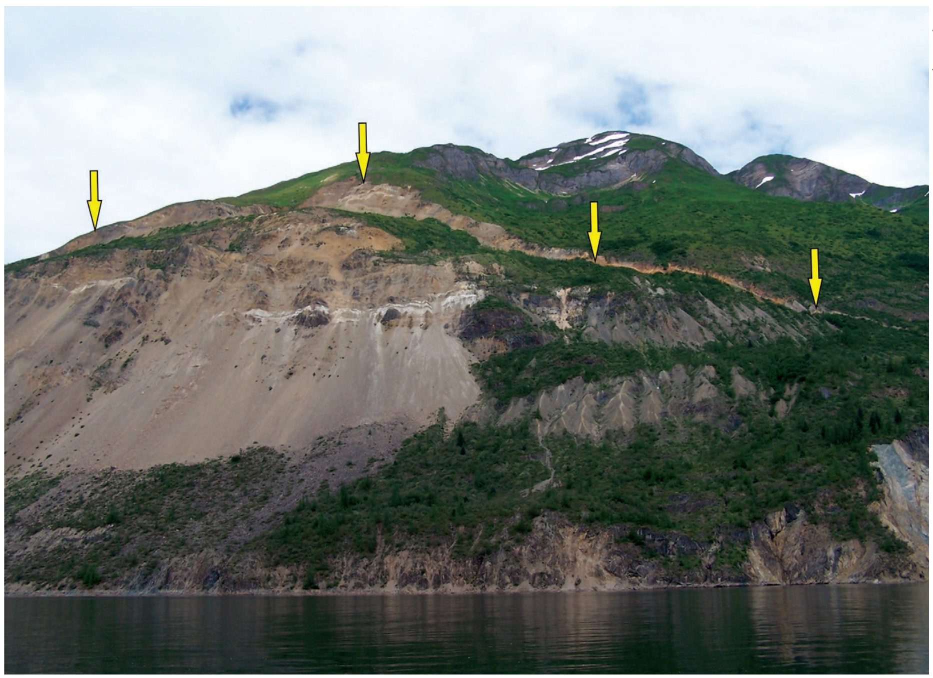


Figure 3. This unstable, sagging slope resulted from glacial retreat in Tidal Inlet, Glacier Bay NPP. Note the prominent scarp (arrows). Research by USGS indicates that rapid collapse of a large perched rock mass could generate a giant wave (tsunami) in Tidal Inlet and the adjacent West Arm of Glacier Bay.

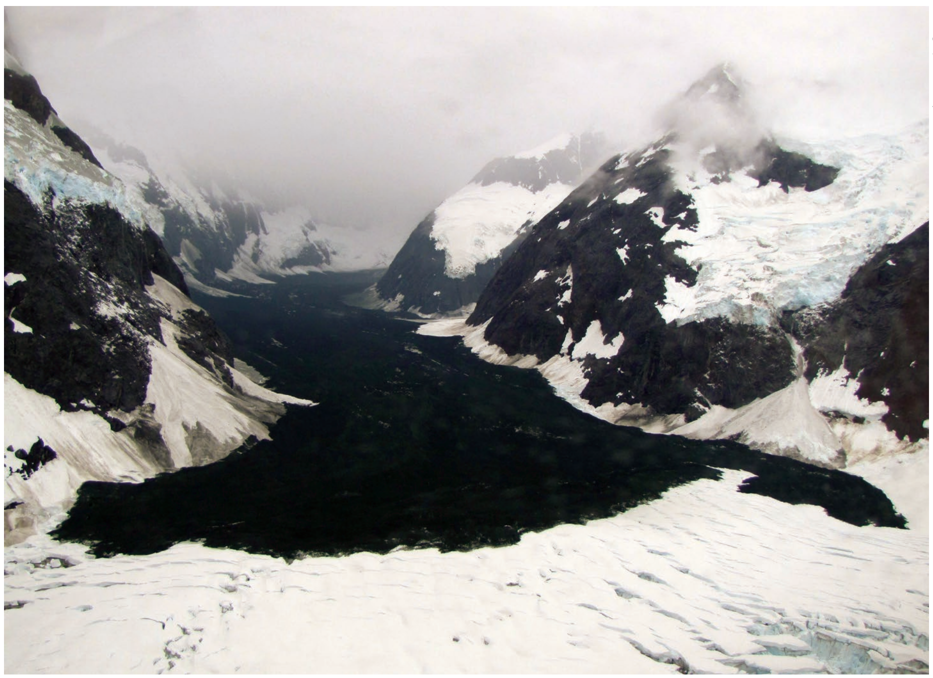
2006; Gruber and Haeberli 2007; Huggel et al. 2008, 2012). The influence of permafrost on rock instability involves many processes, including fracturing and cleft widening by the formation of ice, strength reduction by thawing and water percolation, and perhaps resealing by surface freezing (Gruber and Haeberli 2007; Hasler et al. 2012).

Three very large rock-ice avalanches have occurred on steep and rather cold bedrock slopes in the St. Elias Mountains within the past decade (Figure 4, 7; Huggel et al. 2008, Lipovsky et al. 2008; Geertsema 2012). The Mount Steller, Alaska event occurred at the end of a particularly warm summer (2005); the Mt. Steele, Yukon (2007) and Mount Lituya, Alaska (2012) events seem not to be directly related to a particularly warm summer or year. Huggel et al. (2008) modelled the thermal regime of Mount Steller, which highlighted a potential warming effect on underlying rock of the ice covering the summit. High summit glaciers such as the one on Mount Steller, may play a role in catastrophic rock-ice avalanches in other cold mountain ranges (Huggel et al. 2012).

Interactions between ice cover and underlying permafrost are diverse and complex. Nevertheless, enhanced warming of permafrost and the entry of meltwater into rock fractures are likely to be involved, at least to some extent, in the three events mentioned above. Firn temperatures in cold areas are strongly dependent on the amount of meltwater (Hoelzle et al. 2011). An increase in melt during the warm period 1990 to 2005 (Pleasant Camp climate station, Environment Canada) likely led to a gradual warming of the ice cover. If this meltwater reached the underlying permafrost it could reduce rock strength along discontinuities in the bedrock (Gruber and Haeberli 2007; Hasler et al. 2012).

Event chains

Geomorphic events rarely act in isolation. A rockslide can transform into a rock avalanche or debris flow at the base of a steep slope if it encounters water-saturated soils, snow, or glacier ice. A landslide can also impound a stream, producing upstream flooding or a downvalley flood if the dam fails. Flooding from glacial outburst floods can erode stream banks



Photograph courtesy of Drake Olson

Figure 4. The 2012 Mount Lituya rock-ice avalanche in Glacier Bay National Park, Alaska, travelled more than five miles (8 km) over a glacier.

NPS photo by Robert Winfree

Figure 5. Hidden Lake is formed by annual runoff that collects behind Kennicott Glacier in Wrangell-St. Elias NPP. This 2010 photograph was taken a few weeks after the lake drained rapidly underneath the glacier, leaving icebergs stranded on the drained lake bottom. Note strandlines (between arrows) marking previous lake levels. The highest icebergs on the slope mark the minimum limit of the most recent pre–outburst flood lake level. Glacial lake outburst floods, or jökulhlaups, have been reported from several Alaska parks over the last few years.

Photograph by TEMSCO Helicopters, Inc. from NPS 2010.

Figure 6. This moraine dam failure discharged some 10 million yds^3 (8 million m^3) of mud and sediment into West Creek, a tributary of the Taiya River in Klondike Goldrush NHP, in 2010. The dam burst caused a large flood downstream in KLGO, endangering human life and damaging property and park resources.

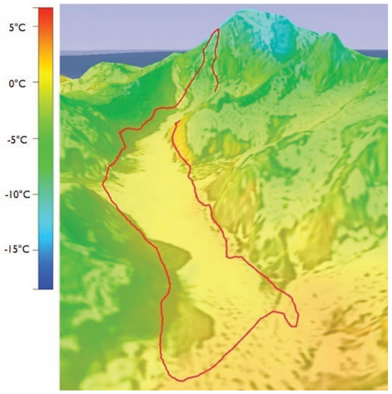


Figure 7. Outline of the 2012 Mount Lituya landslide (red outline), and typical mean annual ground surface temperatures draped over a Google Earth image; view west. The main scarp of the landslide is in a zone of cold permafrost (colder than -10ºC) . Permafrost layer from the Province of British Columbia.

and trigger landslides and debris flows. Landslides can generate large displacement waves such as the 1700-foot wave in Lituya Bay in 1958 (Miller 1960).

Conclusions

Alaska's parks are dynamic and are undergoing constant geomorphic change as glaciers and streams erode and cliffs collapse. Based on climate projections, some permafrost in Alaska will thaw, and many glaciers will thin and retreat, over the remainder of this century, uncovering potentially unstable valley walls. Both permafrost thaw and glacier thinning will contribute to an increase in the incidence of landslides.

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The Long-Term Threats from Climate Change to Rural Alaskan Communities

By Don Callaway

The traditional way of life in much of rural Alaska is at risk. Alaska Native and long-term non-Native villagers are undergoing a series of challenges related both to climate change and to deteriorating economic circumstances. Rapid climate change brings a multitude of physical impacts to villages from erosion, subsidence, floods, changing terrestrial habitats, large-scale melting of sea ice, thawing permafrost and storm surges that in some cases require significant emergency response efforts, massive investments in infrastructure and/or full-scale community relocation (Callaway 2000).

Other climate changes include shifts and dislocations of subsistence species that have the potential to interrupt traditional sharing practices and compromise subsistence contributions to diet. Changes in subsistence harvests, can, as we shall describe later, have drastic impacts to social networks, which can in turn have substantial impacts to emotional and physical health. These two impacts of climate change often receive less emphasis than they deserve, although a major exception to this generalization is the work produced by the Center for Climate and Health, a division of the Alaska Native Tribal Health Consortium (ANTHC, see Brubaker et al. 2012).

Two of the traditional adaptations to deal with environmental and subsistence uncertainty have been to:

Figure 1. A young boy's attempt to build a beach wall for his community of Kivalina. In the background you can see the effects of storm surges which have defied previous attempts to mitigate beach erosion.

Photo courtesy of Michael Brubaker, Alaska Native Tribal Health Consortium

1. Have flexible harvest strategies and compensate for short falls in one resource type by harvesting more from other available resource categories (e.g., see Kivalina below).
2. Utilize social networks, which spread the risk from uncertainty, by sharing available subsistence harvests, technology, labor and income widely within and between extended families.

Both these strategies, as we will describe below, are currently being compromised by climate change.

<u>1. Resilience - Flexible Harvesting Strategies:</u>

The ecosystems in which traditional Alaska Native communities were embedded exhibited far less diversity of animal and plant species than can be found at lower latitudes; they also exhibited dramatic seasonal variation in both the number of species and the density of those species. Both these factors contribute to making Alaska Native communities more vulnerable to the current dramatic changes in arctic ecosystems.

One traditional (and ongoing) strategy for combating fluctuating resources is to harvest multiple species and to trade any excess harvest to other communities. This usually takes the form of coastal communities trading marine mammal products inland in exchange for land mammals or fish.

Another strategy employed by Inupiat and others is to maintain a consistent amount of harvest in terms of pounds over time by varying the composition and proportion of those harvests on a year to year basis. Figure 2 demonstrates this strategy for the community of Kivalina.

In general, when one resource such as marine mammals become unavailable or inaccessible, harvesting more of another resource, e.g., caribou or white fish, tends to make up the shortfall (Figure 3). Climate change has the potential to severely impact both strategies mentioned above and in fact is already doing so. Some preferred marine mammals such as walrus and seal populations are already in sharp decline with the retreating arctic ice cap, caribou have already suffered a 50% decline throughout the arctic, and parasitic organisms such as Ichthyphonus (associated with warmer waters) are starting to infest salmon stocks. Thus, climate change presents a new, more encompassing threat, in that multiple subsistence resource categories maybe at risk at the same time, although from different climate drivers. These impacts limit the opportunity within a community to ramp up the harvest of alternative species.

<u>2. Resilience – Sharing though Extensive Social Networks:</u>

In general, the most substantial traditional practice to limit the risk of starvation involves a complex strategy of sharing harvests within and between extended families. This strategy has historically evolved into social networks that dynamically share and reciprocate subsistence resources, cash, and domestic labor (e.g., babysitting) relationships that exist within and between extended families, although current basic household units often live in separate dwellings (Figure 3). These transactions and relationships buffer and adapt indigenous communities to change and scarcity, scarcity in the availability of subsistence species, scarcity in employment and wage work, and the vicissitudes of services delivered by state and federal entities. It

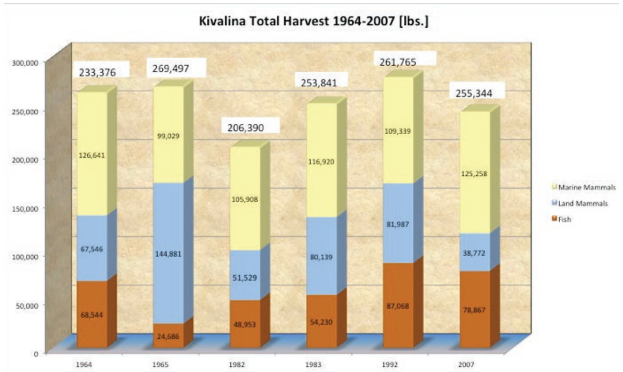

Figure 2. Subsistence Harvests in Kivalina over 3 Decades
Estimated TOTAL Harvest: 1964, 1965, 1982, 1983, 1992, 2007

is the potential breakage of these dynamic exchanges and sharing behaviors that constitutes climate change' greatest threat especially when other stressors such as mineral development add to the cumulative effects.

Jim Magdanz's research in Northwest Alaska clearly demonstrates the resilience of the extended family as an essential entity. Over the last decade and a half research in northwest Alaska has documented the extensive nature of sharing networks in rural indigenous communities. To illustrate contemporary adaptations we will use the small community of Deering in Northwest Alaska as an example. While one of the smallest communities in northwest Alaska with about 125 people, it is fairly representative with respect to income and per capita harvest amounts.

An earlier article in Alaska Park Science described in some detail the sharing networks between extended families in the communities of Wales and Deering (Callaway 2003), and was based upon an extensive ADF&G Technical Paper (Macgdanz et al. 2002).

In this article we focus on the internal interactions, the exchanges within one extended family in Deering to indicate how a combination of subsistence harvests, wage income, and steady but low "unearned" income allows the primary unit in Alaska Native traditional society to sustain itself. This example highlights the dependency on subsistence foods and the key roles of extended family households in obtaining income to sustain both their subsistence activities and other basic needs for survival, e.g., fuel for heating and transportation. Figure 4 expands the attributes of Social Network A in the community of Deering. All five households are related, each household being either a son or a daughter to the active woman in household #19 (whose husband is deceased). Having one of their children live with their grandmother further links two households, #2 and #27.

Household #32, termed a developing household (household head is younger than 39 years of age), is occupied by a couple, one of whom is a wage earner that provides about 90% of the wage income for the entire social/extended kin network.

The single male in household #21 provides nearly 60% of the total harvest of wildlife resources for the entire network. Finally, household #19, the matriarch for the network, provides nearly 60% of the unearned income, primarily in the form of social security, a small but steady source of income, for the entire extended family.

This diagram dramatically illustrates how income both earned and unearned and wildlife resources are pooled within the extended family to provide security and resilience for all five households. No household can survive independently but by sharing resources such as income, labor and food this social entity is buffered against fluctuations in both the social and natural environment.

Thus we see that the major traditional adaptation strategies, the harvesting of a variety of wildlife resources that are shared intensively within the extended family and with much less frequency with other households and networks within the community are a major pillar of the resilience of traditional society throughout Alaska.

Declining Economic Circumstances Exacerbate Climate Change Impacts:

In addition to profound changes in the geophysical environment, we find severe impacts to the ecology of subsistence species and dramatic impacts to the infrastructure of communities. Also becoming prominent are deteriorating economic conditions that include increasing unemployment, decreasing flows of money and services to rural areas all coupled with spiraling increases in cost of living as rising energy prices preclude many households from heating their houses and/or purchasing the gas and technology needed for hunting and fishing.

<u>Institutional Failures:</u>

Space does not permit a detailed description of the institutional failures that exacerbate climate change impacts to coastal (and riverine) rural communities such as Newtok. Emigration or relocation of families within impacted communities to larger communities is usually one of the first suggested institutional responses. However, such

Figure 3. The annual harvest per household, at about 113,400 kg (250,000 lbs.), remains fairly consistent over time although the proportional contribution from fish, land mammals, and marine mammals varies from year to year. For example, the proportional contribution from fish and land mammals changes rather dramatically between 1964 and 1965.

Year	Marine Mammals	Land Mammals	Fish
1964	48%	26%	26%
1965	37%	54%	9%

proposals almost always underestimate the total costs because they do not factor in indirect costs such as new demands on the school system (requiring more teachers and more buildings), and infrastructure additions such as roads, sewer, and water treatment plants. In addition, previous experience (e.g., the relocation of the community of King Island) has demonstrated post-relocation problems from increased drinking, domestic violence and other social problems. Uprooting your entire life is traumatic and brings with it tremendous stresses. Contributing to these stresses is the fact that male hunters lack traditional access to the hunting areas in their new communities. In addition, they lack the necessary finely grained knowledge of the new landscapes to hunt effectively. Households moving into new communities may not receive the respect and political influence that they enjoyed in their home community, and most importantly social networks rarely transfer intact and the underlying support that households and families enjoyed in their home communities maybe fractured or may cease to function altogether.

A GAO report indicates about 190 rural Alaskan communities are at considerable risk from erosion and flooding as the impacts of climate change ramify through the next few decades (GAO 2003). For Alaska alone and interpolating, based upon per household costs from Shishmaref, it could cost $34 billion dollars to relocate the 192 communities currently at risk or exhibiting substantial vulnerability over the next decades. This is an enormous amount of money and in current dollars is about equal to the gross domestic product of the entire state of Alaska for 2009.

Linked to this issue of cost is the enormous problem of coordination and logistics between multiple bureaucratic entities that are responsible for providing federal, state and regional responses to communities affected by climate change. Proposals to relocate families to larger, more secure villages have been rejected by numerous communities (including Newtok, Shishmaref, and Kivalina). The reasons expressed for the rejection of these alternatives center on loss of ready access to

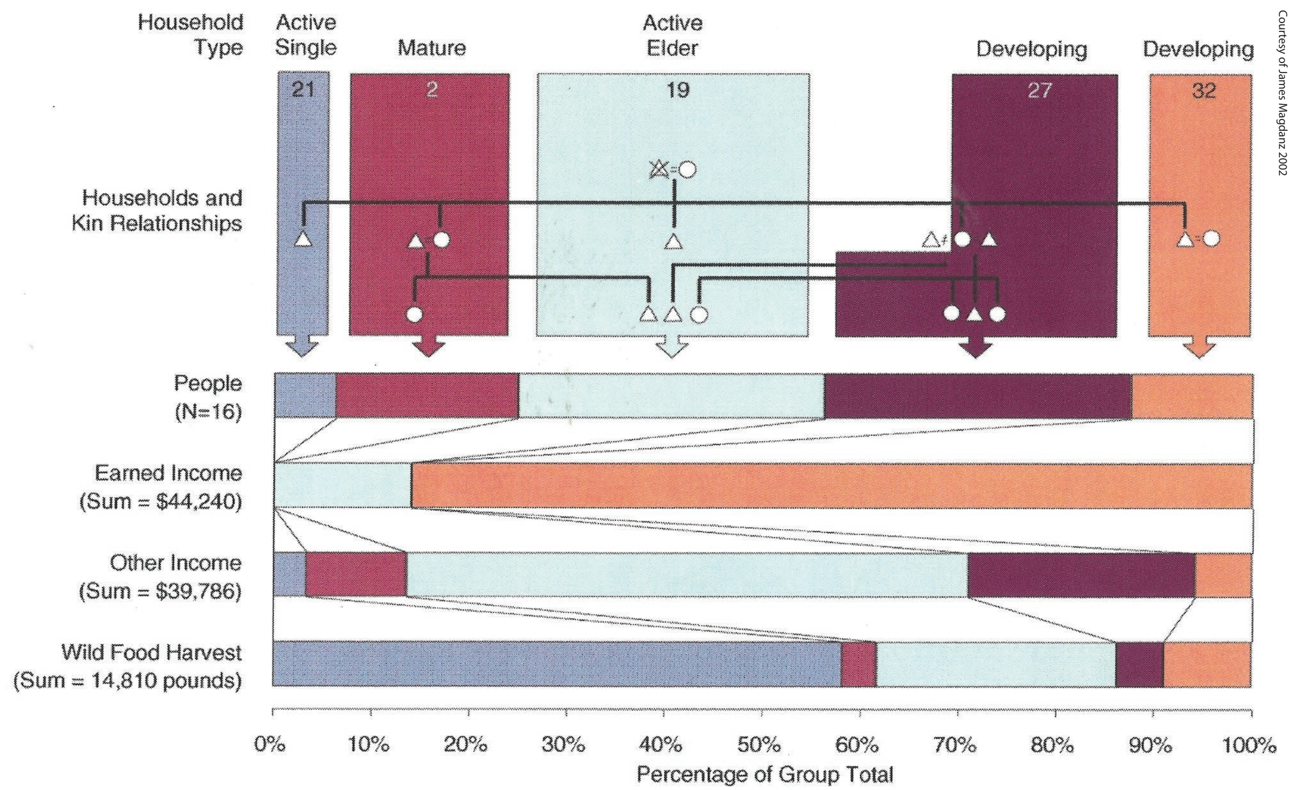

Figure 4. Social Network "A" Subsistence and Economic Relationships, Deering.

well-known subsistence resources, loss of history and a sense of an intact community and fear of loss of support from extended kin (social networks) integral to survival.

The possible relocation of extended families or whole communities to more urban areas is most disturbing. Such a dislocation can destroy traditional social networks, as seen in the outcomes of Russian policy in the Soviet Far East during the 1950's. During this period a number of isolated settlements in Chukotka were declared to be "settlements without prospects." Based on a concept of centralized delivery of services, these communities were struck from centrally planned budgets and were effectively left without fiscal resources with which to maintain community infrastructure. Left with no choice many families relocated to larger and more "centralized" communities. These families are still feeling the repercussions of these relocations, as levels of alcoholism, domestic violence and social disintegration are ubiquitous. In Alaska, whether deep-seated cultural values of sharing and supporting social networks can survive the destruction and relocation of their communities in an incoherent political and bureaucratic structure seems extremely problematic.

Health Impacts Linked to Climate Change:

As climate change restructures the environment, a number of current and potential health problems have also begun to impact rural individuals, families and communities (AAG 2010).

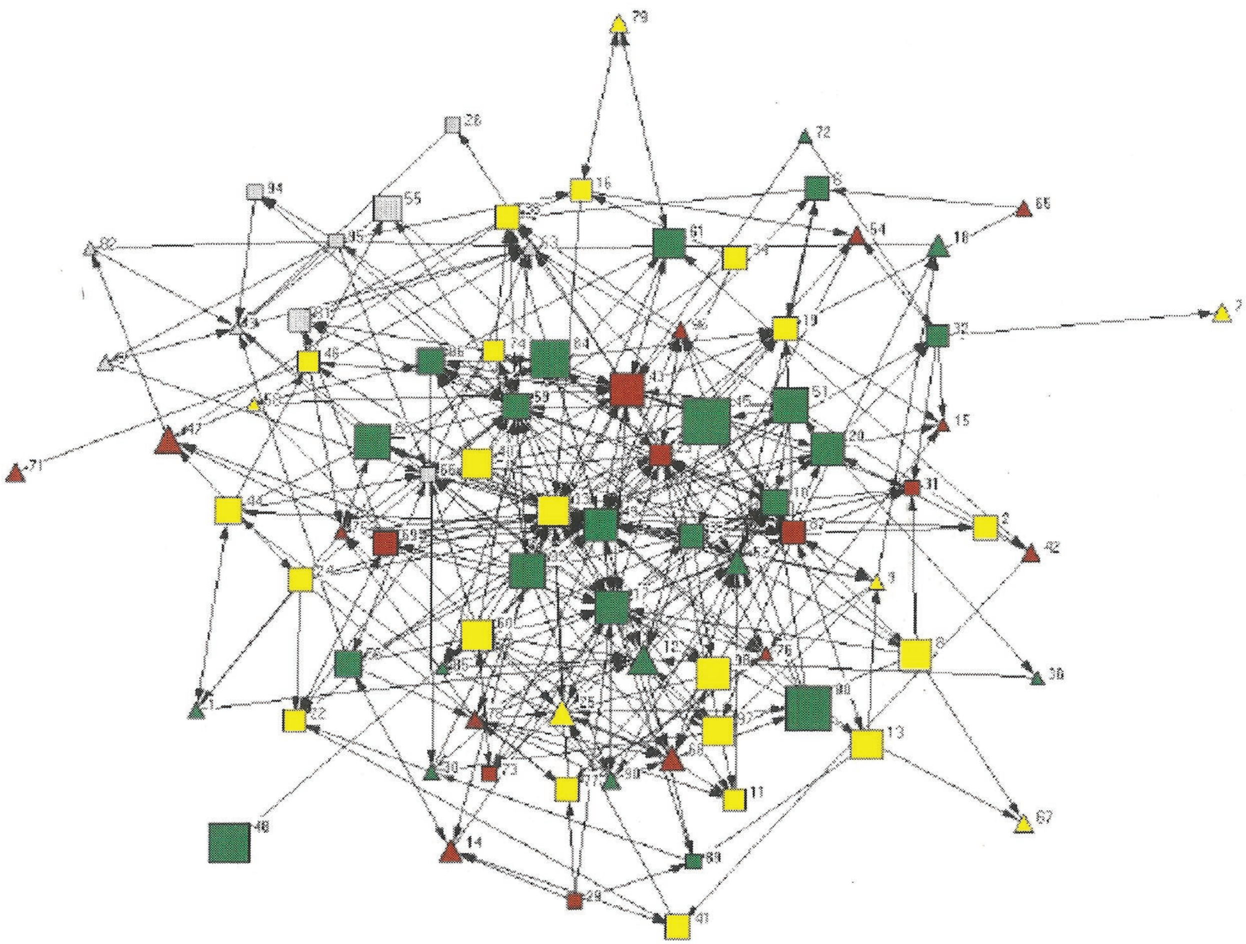

Figure 4. Social network derived by Jim Magdanz using Netdraw.

Diseases:

Increasing temperatures have enabled new diseases to expand in Alaska - such as Vibrio parahaemolyticus and gastroenteritis in Prince William Sound oysters. Epidemiologists have noticed increases in the number and extent of existing diseases such as botulism (e.g., Shishmaref), paralytic shellfish poisoning, giardiasis; Trichinella from walrus; and anisakiasis from anadromous and marine fishes. Also noted is a geographic expansion of diseases such as Giardia (as beavers expand their territories) and increases in bacterial skin infections from a variety of sources.

Projections indicate a greater number and extent of diseases including Echinococcus multilocularis (parasitic tape worm disease), and a greater incidence of skin infections. In addition there is considerable concern about the emergence of new or existing vector-borne diseases as temperatures become warm enough to support ticks, different species of mosquitoes, etc. (e.g., West Nile virus, Lyme disease, tularemia) and the emergence of new viral diseases transmissible to humans from rodents due to expanding populations and latitudinal shifts in distribution (e.g., "roboviruses" in white footed deer mice and voles).

Finally, collapsing community infrastructure has already affected some communities (e.g., Newtok) and is projected to impact many more communities, for example when collapsing of sewage containment structures or land fills cause an increase in disease-based health problems.

Air Quality:

Climate change induced increases in forest and tundra fires (e.g., over 11 million acres burned in 2004/2005 have contributed smoke and other respiratory irritants to the atmosphere, resulting in respiratory disease exacerbations.

Water quality and availability issues:

Climate change brings decrease in quality of potable water from drought (e.g., Nanwalek and Mountain Point), saltwater intrusion, source depletion, permafrost aquifer loss (e.g., Kwigillingok), seawater surges overtopping and contaminating freshwater reservoirs (e.g., Numan Iqua in 2004). Projections indicate more of these impacts leading to increasing health problems for communities and individuals.

Injuries:

Climate change is resulting in thinner shore-fast ice, sea ice, and river ice, with increasing probability of injury and death (e.g., a recent death in Shishmaref); increased possibility of injury and death from separated ice (e.g., North Slope); increased possibility of injury and death from exposure to more intense or more frequent storms (e.g., whaling boat capsized near Gambell due to unusually rough seas, killing four people); and greater injuries from increased icy road conditions throughout much of the state.

Insect and other bites and stings:

Currently the state is experiencing increases in yellow jacket (an expanding population linked to climate warming) attacks (two deaths in Alaska in 2006) and spider bites.

Toxic exposure:

Currently new toxic chemical exposures are occurring as landfills with barrels containing toxic chemicals thaw. In a curious feedback it is projected that there will be increasing exposure to pesticides as they are introduced to control mosquitoes carrying West Nile virus (itself an outcome of increased warming trends).

Extreme events:

As we are currently experiencing increases in extreme events such as flooding, fires, heat waves, and storms; possible infrastructure failures; possible introduction of new diseases; and clinical issues resulting from community and individual response to adverse socio-cultural and economic circumstances (e.g., failures in fisheries and subsistence activities) there will be greater demands on health care and emergency response systems, especially during major events.

Psychological impacts:

At numerous gatherings, people throughout the state, but especially rural Alaskans, express concern and depression about present changes and projected future changes to Alaska's climate and the resulting impacts on culture, subsistence, traditional knowledge and ways of knowing, fish, and wildlife. In addition, continuing losses in community infrastructures, community relocation and dislocation, and changed winter recreational activities all have the potential to impact the rural Alaskan way of life. All these impacts portend drastic outcomes for mental health, community wellness, family integrity, and potential increase in alcoholism, drug use, and other destructive coping behaviors.

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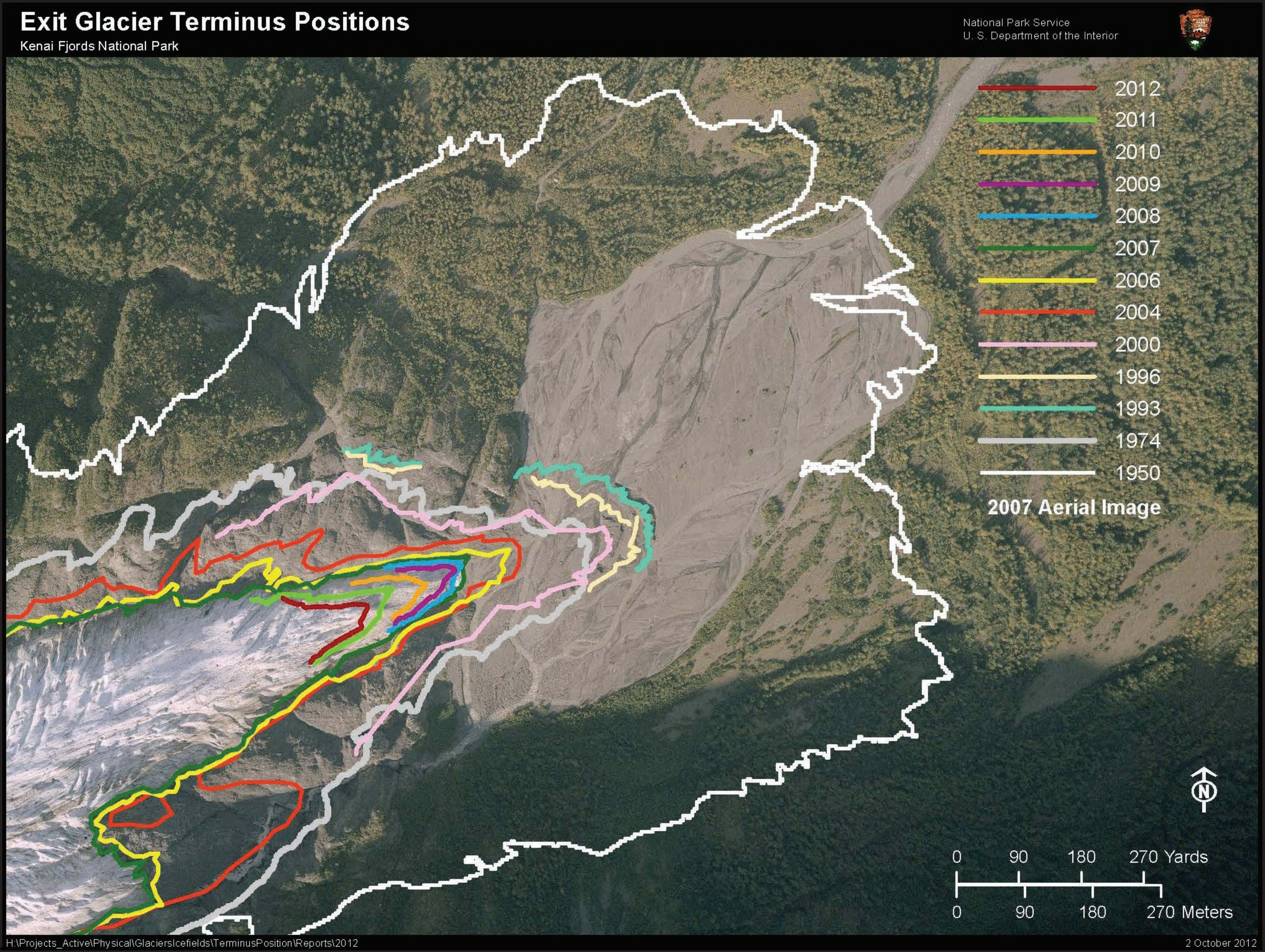
Exit Glacier Terminus Positions
Kenai Fjords National Park
National Park Service
U. S. Department of the Interior
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2 October 2012

NPS Alaska Planning and Designs for the Future with Climate Change

By Bud Rice, Brad Richie, Paul Schrooten, and Jennifer Barnes

Until fairly recently, most National Park Service (NPS) planners, engineers, and architects had not factored climate change into their designs for projects in Alaska. Planners relied on the Environmental Atlas of Alaska (Hartman and Johnson 1978) as an important reference for 35 years, but the book is now out-of-date and out-of-print. Conditions in Alaska are not static. Fortunately, permafrost thaw was a major consideration for the design and construction of the Trans-Alaska Pipeline System (built in 1974-77), but planning based on past environmental conditions created problems for other facilities and infrastructure projects that were constructed both before and after the pipeline project. For examples, roads, residences and other structures in the Fairbanks, Alaska area have tilted or buckled where permafrost thawed beneath them. The U.S. Forest Service visitor center at Portage Lake originally featured views of Portage Glacier calving into the lake, but the glacier has since retreated from view. Visitors come to Exit Glacier in Kenai Fjords National Park for up-close iconic views of the glacier, but the glacier terminus has thawed back rapidly in recent years, causing NPS to chase the retreating glacier (Figures 1 and 2) with trail extensions. Planners and designers have previously assumed a somewhat static environment, but as these and other examples show, such is not the case today.

Rapidly changing conditions in the Arctic are due largely to sea ice retreat and reduced albedo in summer (Comiso et al. 2008, http://www.nasa.gov/topics/earth/features/2012-seaicemin.htmlreferences), which feeds back to accelerate melting of snow, ice, and permafrost in the area. Climate-induced changes in Southcentral and Southwestern Alaska have slowed in recent years, presumably because of a switch in the Pacific Decadal Oscillation (PDO) from a warm phase, from about 1976 to about 2006, to the cold phase of the PDO in recent years (Wendler et al. 2012). Though winters and summers have been cooler in the southern parts of Alaska in recent years, glaciers have continued to retreat overall from previous decades (Molnia 2008, Molnia and Puckett 2008, and McKittrick et al. 2011). Increased precipitation in the southern half of the state onto recently deglaciated terrain and unvegetated barrens with reduced water storage has resulted in increased potential for flashy hydrological conditions (http://en.wikipedia.org/wiki/Retreat_of_glaciers_since_1850#Alaska, http://www.wunderground.com/climate/Glaciers.asp#Header1_6).

In the southern half of the state, the NPS has been contending with higher risks of flooding or other effects from glacial retreat. In coastal areas storm surges on top of sea level rise, tidal fluxes, and permafrost thaw, which has been monitored across the Alaska for a few decades (Romanovsky et al. 2012 and Ostercamp 2008), have increased risks to natural and cultural resources and infrastructure in these areas.

Increased incidence of beetle-killed trees, presumably resulting from warmer winters (Juday and Marler 1997, Juday et al. 1997, http://www.cgc.uaf.edu/newsletter/gg6_1/beetles.html, http://e360.yale.edu/feature/whats_killing_the_great_forests_of_the_american_west/2252/, http://www.usgcrp.gov/usgcrp/nacc/education/alaska/ak-edu-refs.htm) and dry warm summers have resulted in massive wildland fires in Interior and Southcentral Alaska. Two of the three largest fires seasons on record occurred in 2004 and 2005, burning about six million and 4 million acres, respectively.

Federal Policies on Climate Change and Environmental Analysis

In 2009, NPS issued interim guidance for considering climate change in environmental analysis (NPS 2009), and recommend that two key questions be addressed:

1. What is the contribution of proposed project to climate change, as indicated by greenhouse gas emissions associated with the project?
2. What is the impact of climate change on park resources, and specifically, the resources that will be impacted by the project?

The White House Council on Environmental Quality's Draft NEPA Guidance on Consideration of the Effects of Climate Change and Greenhouse Gas Emissions also recommended for consideration of climate change in NEPA analyses of environmental effects and reasonable alternatives to mitigate impacts, including:

1. The greenhouse gas emissions effects of a proposed action and alternative actions; and
2. The relationship of climate change effects to a proposed action or alternatives, including the relationship to proposal design, environmental impacts, mitigation, and adaptation measures.

In November 2012, NPS Director Jon Jarvis released the National Park Service Climate Change Action Plan (NPS 2012a). The goal of the plan is to build flexible, coordinated capacity to deal with climate change.

Figure 1. Map of Exit Glacier terminus from 1950 to 2012.

This plan lays out "no-regrets" actions that parks can take now and in preparation for future conditions. Jarvis stated, "While the plan lays out specific actions, flexibility is a key component. Even as we embrace the uncertainties and dynamic nature of climate change, we know that new information, technologies, and ideas will emerge over the coming years to help us respond. The National Park Service is making changes in its operations because of what we've learned about climate change."

An expanding body of empirical evidence and national policies make it clear that climate change needs to be considered and factored into a wide range of project planning including but not limited to: the design and location of buildings, roads, and trails; management of wildland fires; and in natural and cultural resources management (see DeGange et al. and Winfree et al. in this issue). This article focuses on examples from planning for wildland fire management, facilities design, and road and trails location.


NPS Photograph

Figure 2. Exit Glacier in 1998.

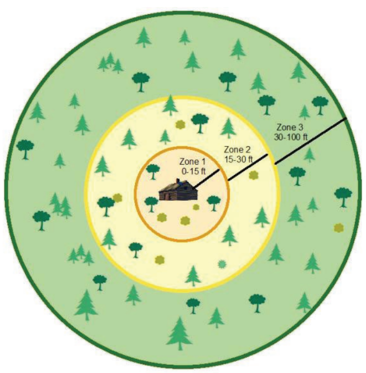

NPS Photograph

Figure 3. Hiking towards Exit Glacier 2008.

Wildland Fire

Historical evidence and modeling indicate that woody vegetation, shrubs and trees, are expanding to higher altitudes and higher latitudes with more frequently and widespread incidence of forest pests and diseases (Vose et al. 2012). University of Alaska Scenarios Network for Alaska/Arctic Planning (SNAP) modeling indicates high probability of warmer and drier conditions in the future. With warmer and drier conditions, the potential for fire is likely to increase. More area burned in Alaska in the last decade than the previous 50 years of records (Kasischke et al. 2010), although this was largely driven by the fire seasons of 2004 and 2005. Evidence also suggests that environmental changes in the Arctic may be affecting tundra fire regimes. For example, during the summer of 2010, thirty-seven fires occurred in the Noatak National Preserve, the largest number of fires occurring in this area since record keeping began in 1950. Three years prior, the Anaktuvuk River Fire on Alaska's North Slope, more than doubled the recorded area burned north of the Brooks Range (Higuera et al. 2011). Although wildland fires have not been nearly as dramatic since 2004/05, NPS recognizes that severe conditions could return any year, and it is best to be prepared.

The NPS Alaska Region is currently preparing an environmental assessment to address a management plan to reduce hazardous vegetative fuels within several parks in Alaska (not to include Denali National Park, which already has such a plan in place, or Southeast Alaska rainforest areas). The plan proposes to conduct hazardous fuel reduction projects around infrastructure, values at risk or near communities adjacent to park lands in order to provide defensible space and to help mitigate wildfire risks. This plan builds upon existing park fire management plans and the Alaska Interagency Wildland Fire Management Plan of 2010. Specifically the plan proposes to adopt Alaska Firewise concepts to clear fire-prone vegetation with appropriate methods from around structures in developed areas (Figure 4) and remote backcountry settings. Furthermore, the



Jennifer Barnes, NPS Fire Ecologist

Figure 4. Schematic of fuels treatment zones around a structure.


NPS Photograph

Figures 5 and 6. Denali Visitor Access Center with fuels reduction treatments.


NPS Photograph

Figure 6. After fire fuels treatment.

Figure 7. Denali Wilderness Access Center.

Figure 8. Western Arctic Parklands - Northwest Alaska Heritage Center foundation & final building

Figure 9. Duplexes on permafrost in Nome, Alaska, Bering Land Bridge National Preserve.

Figure 10. Gates of the Arctic Coldfoot Housing on adjustable post and pad foundation.

Figure 11. The Denali Talkeetna (Walter Harper) Ranger Station was constructed on an elevated pad and hardened base within a floodplain.

NPS is considering whether, where, and when to use prescribed fire to enlarge protection zones around structures set amid particularly fire-prone vegetation types such as black spruce or beetle-killed white spruce.

The NPS Fire Management program has reduced hazardous fuels around the Denali Wilderness Access Center as part of a front country fuels reduction project to reduce the risk of wildfire (Figures 5 and 6). The pre-treatment photo on the left shows thick, flammable spruce and the photo on the right shows one year post treatment with the spruce cleared adjacent to the building. The fire ecology program has monitored these sites to determine effectiveness of the fuels project.

Facilities

In Denali National Park and Preserve and in Arctic NPS areas, several buildings have been constructed with consideration of permafrost thaw. The Wilderness Access Center near the entrance to Denali National Park was constructed on "warm" permafrost with a ground temperature just under 32 °F (0°C), also

Figure 12. Glacier Bay Huna Tribal House Site will be built next to ocean, but the surrounding land is expected to rise more quickly than sea level in coming decades due to isostatic rebound in this area.

NPS Photo by Robert Winfree

Figure 13. Storm damage along shore at Shishmaref, Alaska. In Shishmaref, Alaska, where there is an ongoing battle with the rising sea, seawalls made of various materials are being constructed as houses are undermined by severe erosion on the coastline. A wall made of sandbags was the first attempt to keep the water out. Local resident Heather "Anunuk" Sinnok shares her frustration as part of the Portraits of Resilience project: "How are sandbags going to help us? We're made out of sand!! We had such high hopes for the second wall made of cement blocks." The second wall also had little success, and is now sinking into the thawing permafrost beneath the island.

known as the melting temperature. The designers recognized that a slight warming of the ground due to climate change or human activities could result in the complete thawing of the permafrost on which the foundation was built. Consequently, the building was constructed on driven piles with provisions to add refrigerant cooling, if needed, into the pilings (Figure 7).

The relatively new Northwest Alaska Heritage Center in Kotzebue, Alaska was built on driven hollow pilings in an area known to have permafrost (Figure 8). The completed building is elevated completely off the ground and insulated all around. Park housing duplexes for Bering Land Bridge National Preserve in Nome, Alaska were similarly built on pilings driven into permafrost-rich ground (Figure 9). Housing for Gates of the Arctic National Park and Preserve employees in Coldfoot, Alaska (one of the coldest spots in the nation), is constructed on adjustable post and pad foundation to account for changing permafrost conditions (Figure 10).

Permafrost is discontinuous or absent in South-Central Alaska, south of the Alaska Range, except under glaciers. Talkeetna, Alaska, where the Denali climbing rangers base their operations, is located within a floodplain. Here, the NPS visitor and climbing center was built upon an elevated pad and hardened base (Figure 11). The value of forward-thinking design became very clear in September 2012, when a 100-year flood inundated Talkeetna and the surrounding lowlands, devastating many homes and businesses. The ranger station was spared major damages. In spring 2013, the community was again bracing for flooding, with radio programs broadcasting for emergency preparations. Community leaders also requested scenario planning assistance from NPS to prepare for future extreme events.

The land in Glacier Bay National Park and surrounding areas of Southeast Alaska is responding to glacial retreat in a much different way than in Northern Alaska. Here the land has been measured to be rebounding at a rate of about 2 in (5 cm) a year. This effect (isostatic rebound) is a geologic readjustment to tremendous weight removed from the Earth's crust by melt and retreat of the land-based and tidewater glaciers from within the park and surrounding areas. Although sea level is also rising from freshwater inflows and thermal expansion, land surfaces in some areas of Southeast and Southwest Alaska are currently rising even faster. The NPS is preparing to construct the Huna House on the shores of Bartlett Cove near park headquarters (Figure 12). The NPS Development Advisory Board considered elevating the building to account for sea level rise, but concluded that relative sea level rise was not an issue in this particular location. The land around Bartlett Cove is actually expected to rise relative to adjacent sea level for the foreseeable future, due to isostatic rebound. Although a design change was not needed in this case, this example shows the importance of conducting a reasonable assessment of the plausible effects of climate change.

Sea level rise, storm surges, and coastal erosion are severe issues for coastal communities in Western and Arctic Alaska, such as the village of Shishmaref, which is situated amid coastal segments of Bering Land Bridge National Preserve. Thawing permafrost, progressive sea ice retreat, and delayed onset of sea ice formation during fall storm seasons have resulted in the exposure of Shishmaref

NPS photo

Figure 14. NPS photograph of Exit Glacier Road during high water event in 2009.

and other coastal communities to devastating coastal erosion and/or flooding, which threaten buildings and lives (Figure 14). Shishmaref has garnered international press over their plight, and they are requesting funds to reinforce their shoreline with massive rock revetments to buy time for eventual relocation. Both options are extremely expensive, and reduced federal funding complicates the village relocation efforts. With assistance from the State of Alaska, Shishmaref has investigated construction of a road across NPS lands to Native-owned lands at Ear Mountain, where construction materials could be mined and moved to reinforce the existing village site or to a future village site. In this example, we see how climate change pressures on a community outside an NPS area could also lead to environmental impacts (road construction) within the Preserve itself.

Roads and Trails

Addressing the impacts of climate change to park transportation systems is one of the five key goals for NPS in the Long-Range Transportation Plan for Alaska (NPS 2012b). This plan calls for science, adaptation, mitigation, and communication to address impacts on transportation, and also emphasizes implementing

Figure 15. Flood waters washing over Exit Glacier Road in 2010.

Figure 16. Hillside slump impedes traffic at mile 20.5 of Denali Park Road, August 1, 2005.

Figure 17. Maintenance at hillside slump at Mile 20.5 of Denali Park Road, August 1, 2005.

performance measures. Scientific research, monitoring, and a proposed Vulnerability Assessment for Alaska Transportation Infrastructure are needed to understand and respond to climate change challenges to transportation systems in Alaska units. Adaptation is needed to manage existing transportation assets and to plan for new systems in face of climate change. Mitigation will help NPS reduce its carbon footprint associated with park operations and visitation. Communication involves sharing compelling stories about climate change with the public as related to transportation.

The Exit Glacier Road in Kenai Fjords National Park (located between mileposts MP 7 and MP 8), is frequently flooded from the Exit Glacier drainage. This section of the road had not previously been observed to flood during mid-summer months. Over time the flood changed from infrequent to more of an annual expectation during fall of the last couple of years. Here, flooding appears to be associated with intense storm activity and/or increased melt and runoff from Exit Glacier, which damages the road and impedes visitor access to the Exit Glacier area. Park managers also suspect a changing hydrologic regime in the area, possibly due to massive amounts of outwash material deposited in the outwash plain below receding Exit Glacier and in Exit Creek delta with its braided streams. These changes contribute to massive water flows that overwhelm the road (Figures 15 and 16). While new studies are being conducted to verify presumed causes of the unusual flooding events, the NPS is also redesigning the road to address the recurring problem.

In Denali National Park, mud and vegetation slumps onto the Denali Park Road "more frequently and aggressively than in the old days" according to long-term east district road maintenance foreman Tim Taylor. The park road was cut into mostly south-facing slopes where permafrost lays at depth beneath, but other contributing circumstances have also been building for decades. Clearing and widening of road ditches and annual clearing of culverts of debris, may have led to more thaw and sliding of vegetation above permafrost beds. In places, huge cracks have opened in the tundra above the road, and some slumping has also occurred below the road. One example of these events is at mile 20.5 of the park road (Figures 17 and 18), where maintenance workers are responding with fixes to minimize road closures. The NPS recognizes that human activities play a role in these events, but with his 33-years' park experience to draw on, Taylor says these slumps are now more frequent, widespread, and larger than decades before. He suspects that something bigger is affecting the road. Ongoing NPS natural resources inventory and monitoring may help to reveal the answers.

In summary, Alaska's national parks face new and unexpected planning, design, and maintenance challenges as we enter a new era of climate change. It behooves the NPS to pay attention to these changes and plan and act accordingly. Foresight and flexibility are extremely important in dealing with highly uncertain future conditions, including changes resulting partly or wholly from climate change. A temporary cold phase of the PDO appears to have recently slowed or reversed recent warming trends south of the Arctic, as compared to previous decades, but atmospheric changes are still occurring. Localized cooling trends could quickly reverse or be overwhelmed by wider-scale changes. Nimble and prudent planning, and preparations for plausible future conditions resulting from climate change effects, are warranted and desirable.

Figure 18. Landslide near Sable Pass, Denali Park Road, October 2013.

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Arrange for Change
CHANGE has always been a powerful force of nature. National Parks tell stories that help us understand and appreciate how our lives are
Climate Change is Happening
Warmer winters and longer, more intense periods of melting have increased the rate of glacial retreat in many parks, as demonstrated by the Northwestern Glacier at Alaska's Kenai Fjords National Park. It is estimated by scientists from the U.S. Geological Survey that by 2020, many of the glaciers in Montana's Glacier National Park will be completely gone.
In Yosemite, the pika population is in danger of extinction as warming temperatures are shifting their cool habitat higher and higher on the mountainsides. Eventually, if warming continues, they may have nowhere higher to go.
There is Much We Can Do
Parks are performing evaluations through "Climate Friendly Parks Workshops," in partnership with the Environmental Protection Agency, to evaluate energy usage and gain efficiencies where possible. During the workshops, managers develop practical strategies to reduce emissions.
Many parks have on-going research and monitoring of vulnerable resources and several have climate science researchers specifically addressing indicators that relate to climate change impacts.
Perhaps one of the best strategies for coping with change is for each person to become "Carbon Neutral" in their daily lives. This can be accomplished by reducing energy use and investing in practices and alternate technologies that offset the carbon emissions we are generating.
Service is already working to respond to these changes.
We are at this moment participating in one of the very greatest leaps of the human
to a knowledge not only of outside nature but also of our own deep inward myste
- Joseph Campbell

Telling the Stories of Climate Change

By John Morris and Brooke Carney

Communication about the changing climate in Alaska's parks has been underway for over a decade. As the evidence, scientific understanding, and collective knowledge of its causes and implications become better understood, so also have the approaches for discussing it with our many audiences. Throughout the Alaska region, NPS employees are working together and across disciplines to raise awareness about this global issue, provide the best available scientific explanations of its impacts, and cultivate a hopeful response.

In the words of the NPS Director Jon Jarvis, "One of the most precious values of the national parks remains their ability to teach us about ourselves and how we relate to the natural world." Our communication approach is to let the changes occurring in our parks do just that—teach us to be integrated in the natural world, not act in opposition to it.

Shaping the Stories

The Alaska Region's Climate Change Response Strategy, consistent with the NPS national strategy, supports efforts to collaborate and use parks as centers of continuous learning, as indicators of changing climate and trends. It identifies that we use contemporary communication methods to provide products and programs that help audiences understand what is happening in Alaska's parks and how we might respond to changes we're already seeing. To meet professional standards, effective communication products are developed around three primary characteristics: 1) strong relevant messages, 2) defined specific audiences, and 3) appropriate techniques that truly connect the participants to meanings. In this article we will examine some current products and on-going efforts that exemplify best practices.

Figure 1. Earth to Sky partners with the "Arrange for Change" national traveling display.

The Climate Change Response Strategy identifies four key messages about climate change that guide communication efforts in the Alaska Region.

- Climate change is happening and human activities are contributing to and accelerating it.
- Changing climate has consequences for parks, people, and the planet.
- The NPS is responding with practices that address climate change.
- The choices we make now may help to avoid significant impacts in the future.

Communicating about climate change brings unique challenges. New information about the impacts of climate change is emerging all the time. The science used to identify and explain the various phenomena associated with climate change and its effects is often complex. Evidence that covers large areas over longer time scales is often hard for the average person to grasp. Public understanding and perceptions don't necessarily match scientific understanding.

There are many audiences to reach with these messages about climate change. We begin by developing reports and training materials for our internal audiences, —our staffs, managers, and colleagues—to prepare us in preserving and protecting the parks. We've been working to grow and connect to the nearby audiences which include partners, community members, and stakeholders who have history and proximity to the places we manage and the stories they tell. Because this issue of changing climate is so wide-reaching, it requires that we bring together these players more holistically than ever before. New mechanisms are being used to do so, like holding scenario planning or community organizing workshops where all can engage in the dialogue, learn the science, solve the problems, and understand their consequences together, as a community. The changes being discussed will be with us for decades; it's best to have all parties present for the learning phase so when decision points are confronted, everyone has a better understanding of the concerns.

As for external audiences, from students to park travelers to virtual visitors, many additional products will be in demand to reach and keep them informed over the decades to come. As the populations learns to use new technologies, and to absorb information about the world at a faster and faster rate, so too must we stay current and deliver meaningful ways for them to easily engage in their "public" resources. New devices, and new ways of using them, is making the challenge of communicating through interactive and rapidly evolving social media a vigorous and growing demand for interpreters.

With these challenges in mind, NPS staff members are working on communication products and programs that address the needs of many audiences and deliver messages in meaningful and relevant ways. The resulting communication efforts consider both public perceptions (Brownlee et al. 2011, Thompson et al. 2011, Gram et al. 2012) and scientific evidence.

Climate Change Stories, Many Approaches for Many Needs

To assist with public outreach efforts, the Alaska Region has developed several traveling displays that explain the primary principles associated with how climate works, how it's changing, and how the effects of these changes are being measured over the long term. These exhibits are in use year round, in park visitor centers, at national conferences and meetings, and at numerous special events and workshops focused on climate change and sustainability around Alaska. Some of the AKR parks are beginning to develop exhibit panels on this issue as well. One such example, at Kenai Fjords at Exit Glacier, examines how all of us can 'Do Our Part" and responding to climate change and its implications. All of these displays not only provide information and observations to stir the viewer's thinking, they can also provide a catalyst for informal interpretive conversations with rangers and staff about the relevance of changing climate to that location or park. Those conversations are some of the best outreach opportunities and on-going strategies for raising awareness that the NPS has.

Fact sheets and brochures for park visitors and the general public have been developed by various parks and programs. Some help visitors understand the unique local climate and its effects, like explaining the wet seasons of Klondike Gold Rush, while others highlight specific landscape features, such as the rapidly melting glaciers in Glacier Bay. Online videos and podcasts are being created to engage audiences with the sights, sounds, and site-specific conditions that scientists are discovering in the parks. KEFJ podcast, briefing statements, and summaries have been developed to educate internal audiences. Examples include resource briefs and reports on glacier monitoring and change, phenology monitoring and change, and permafrost monitoring and change.

While these and the many other unlisted efforts are a good start, we have a long way to go before all audiences are reached, all stories told, and the overall goal of climate change literacy is reached. Toward that end, there are several efforts currently underway that will be finalized in late 2013 and early 2014. These efforts include a wayside exhibit on phenology at Kenai Fjords' Exit Glacier visitor area, two reports—a technical one and a more general interpretive one—detailing the status and trends of glaciers in Alaska's national parks, and an interactive photography database documenting landscape change in southwest Alaska parks. In addition, a region-wide working group of interpreters, scientists, and partners from the University of AK, SNAP program, are developing a first-of-its-kind, statewide visitor's guide about climate change in Alaska's national parks (http://www.nps.gov/akso/nature/climate/index.cfm). Not only will this publication be available in parks across the state, an electronic version of it will be available online, with many added interactive features to help tell the stories of change from the parks. All of these efforts are contributing to a broad and engaging conversation about climate change, and about us in a world that addresses it.

Figure 2. Doing Our Part exhibit at Exit Glacier Nature Center (KEFJ).

Revisiting Leopold

In 2012, The National Park System Advisory Board produced the "Revisiting Leopold" report. In the report, the committee advises "the American people—including but not limited to visitors and residents of communities near parks—must be recruited as 'co-stewards' of the national parks. The public must be made aware of the challenges facing the National Park System and urged and empowered to take action to preserve and protect these resources as part of their enduring responsibility as citizens." Creating compelling outreach materials is one of the best ways to accomplish this task. Maybe those citizens in the future will be benefactors of an incredible story about the collaborations of civilization that responded in the face of a global event.

Figure 3. National brochure (top) and a park brochure (bottom)

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